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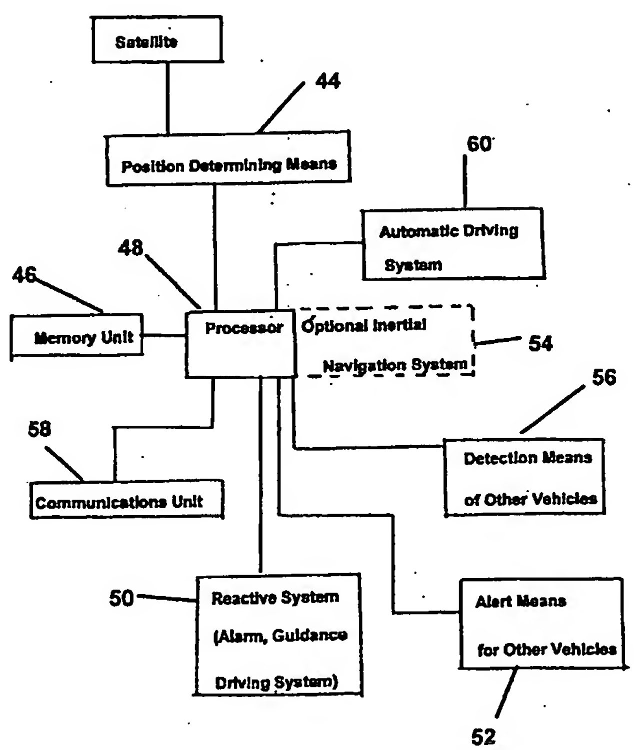
(54) Title: METHODS AND APPARATUS FOR PREVENTING VEHICLE ACCIDENTS

(57) Abstract

System and method for preventing vehicle accidents in which the absolute position of the vehicle is determined, e.g., using a satellite-based positioning system (44) such as GPS, and the location of the vehicle relative to the edges of the roadway is then determined based on the absolute position of the vehicle and stored data (46) relating to edges of roadways on which the vehicle may travel. A system or component within the vehicle is initiated, e.g., an alarm or warning system (50), or the operation of a system or component is affected, e.g., an automatic guidance system (60), if the location of the vehicle approaches close to an edge of the roadway or intersects with an edge of the roadway.



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METHODS AND APPARATUS FOR PREVENTING VEHICLE ACCIDENTS

1. Background of the Invention

1.1 Field of the invention.

This invention is in the fields of automobile safety, intelligent highway safety systems, accident avoidance, accident elimination, collision avoidance, blind spot detection, anticipatory sensing, automatic vehicle control, intelligent cruise control, automotive navigation and other automobile and truck safety, navigation and control related fields.

There are two major efforts underway that will significantly affect the design of automobiles and highways. The first is involved with preventing deaths and serious injuries from automobile accidents. The second involves the attempt to reduce the congestion on highways. In the first case, there are approximately forty thousand (40,000) people killed each year in the United States by automobile accidents and another several hundred thousand are seriously injured. In the second case, hundreds of millions of man-hours are wasted every year by people stuck in traffic jams on the world's roadways. There have been many attempts to solve both of these problems; however, no single solution has been able to do so.

When a person begins a trip using an automobile, he or she first enters the vehicle and begins to drive, first out of the parking space and then typically onto a local or city road and then onto a highway. In leaving the parking space, he or she may be at risk from an impact of a vehicle traveling on the road. The driver must check his or her mirrors to avoid such an event and several electronic sensing systems have been proposed which would warn the driver that a collision is possible. Once on the local road, the driver is at risk of being impacted from the front, side and rear, and electronic sensors are under development to warn the driver of such possibilities. Similarly, the driver may run into a pedestrian, bicyclist, deer or other movable object and various sensors are under development which will warn the driver of these potential events. These various sensors include radar, optical, ultrasonic, and a variety of others sensors, each of which attempts to solve a particular potential collision event. It is important to note that in none of these cases is there sufficient confidence in the decision that the control of the vehicle is taken away from the driver. Thus, action by the driver is still always required.

In some proposed future Intelligent Transportation System (ITS) designs, hardware of various types is embedded into the highway and sensors which sense this hardware are placed onto the vehicle so that it can be accurately guided along a lane of the highway. In various other systems, cameras are used to track lane markings or other visual images to keep the vehicle in its lane. However, for successful ITS, additional information is needed by the driver, or the vehicle control system, to take into account weather, road conditions, congestion etc., which typically involves additional electronic hardware located on or associated with the highway as well as the vehicle. From this discussion, it is obvious that a significant number of new electronic systems are planned for installation onto automobiles. However, to date, no product has been proposed or designed which combines all of the requirements into a single electronic system. This is the intent of this invention.

The safe operation of a vehicle can be viewed as a process in the engineering sense. To achieve safe operation, first the process must be designed and then a vehicle control system must be designed to implement the process. The goal of a process designer is to design the process so that it does not fail. The

fact that so many people are being seriously injured and killed in traffic accidents and the fact that so much time is being wasted in traffic congestion is proof that the current process is not working and requires a major redesign. To design this new process the information required by the process must be identified, the source of that information determined and the process designed so that the sources of information can communicate effectively to the user of the information, which will most often be the vehicle control system. Finally, the process must have feedback that self-corrects the process when it is tending toward failure.

Although it is technologically feasible, it is probably socially unacceptable at this time for a vehicle safety system to totally control the vehicle. The underlying premise of this invention, therefore, is that people will continue to operate their vehicle and control of the vehicle will only be seized by the control system when such an action is required to avoid an accident or when such control is needed for the orderly movement of vehicles through potentially congested areas on a roadway. When this happens, the vehicle operator will be notified and given the choice of exiting the road at the next opportunity. In some implementations, especially when this invention is first implemented on a trail basis, control will not be taken away from the vehicle operator but a warning system will alert the driver of a potential collision, road departure or other infraction.

Let us consider several scenarios and what information is required for the vehicle control process to prevent accidents. In one case, a driver is proceeding down a country road and falls asleep and the vehicle begins to leave the road, perhaps heading toward a tree. In this case, the control system would need to know that the vehicle was about to leave the road and for that it must know the position of the vehicle relative to the road. One method of accomplishing this would be to place a wire down the center of the road and to place sensors within the vehicle to sense the position of the wire relative to the vehicle. An alternate approach would be for the vehicle to know exactly where it is on the surface of the earth and to also know exactly where the edge of the road is.

These approaches are fundamentally different because in the former solution every road in the world would require the placement of appropriate hardware as well as the maintenance of this hardware. This is obviously impractical. In the second case, the use of the global positioning satellite system (GPS), augmented by additional systems to be described below, will provide the vehicle control system with an accurate knowledge of its location. Whereas it would be difficult to install and maintain hardware such as a wire down the center of the road for every road in the world, it is not difficult to survey every road and record the location of the edges, and the lanes for that matter, of each road. This information must then be made available through one or more of a variety of techniques to the vehicle control system.

Another case might be where a driver is proceeding down a road and decides to change lines while another vehicle is in the driver's blind spot. Various companies are developing radar, ultrasonic or optical sensors to warn the driver if the blind spot is occupied. The driver may or may not heed this warning, perhaps due to an excessive false alarm rate, or he or she may have become incapacitated, or the system may fail to detect a vehicle in the blind spot and thus the system will fail.

Consider an alternative technology where again each vehicle knows precisely where it is located on the earth surface and additionally can communicate this information to all other vehicles within a certain potential danger zone relative to the vehicle. Now, when the driver begins to change lanes, his or her

vehicle control system knows that there is another vehicle in the blind spot and therefore will either warn the driver or else prevent him or her from changing lanes thereby avoiding the accident.

Similarly, if a vehicle is approaching a stop sign or red traffic light and the operator fails to bring the vehicle to a stop, if the existence of this traffic light or stop sign has been made available to the vehicle control system, the system can warn the driver or seize control of the vehicle to stop the vehicle and prevent a potential accident. Additionally, if an operator of the vehicle decides to proceed across an intersection without seeing an oncoming vehicle, the control system will once again know the existence and location and perhaps velocity of the oncoming vehicle and warn or prevent the operator from proceeding across the intersection.

Consider another example where water on the surface of a road is beginning to freeze. Probably the best way that a vehicle control system can know that the road is about to become slippery, and therefore that the maximum vehicle speed must be significantly reduced, is to get information from some external source. This source can be sensors located on the highway that are capable of determining this condition and communicating it to the vehicle. Alternately, the probability of icing occurring can be determined analytically from meteorological data and a historical knowledge of the roadway and communicated to the vehicle over a LEO satellite system or an FM sub-carrier or other means.

Studies have shown that a combination of meteorological and historic data can accurately predict that a particular place on the highway will become covered with ice. This information can be provided to properly equipped vehicles so that the vehicle knows to anticipate slippery roads. For those roads that are treated with salt to eliminate frozen areas, the meteorological and historical data will not be sufficient. Numerous systems are available today that permit properly equipped vehicles to measure the coefficient of friction between the vehicle's tires and the road. It is contemplated that police vehicles will be equipped with such a friction coefficient measuring apparatus and can serve as probes for those roadways that have been treated with salt. Information from these probe vehicles will be fed into the information system that will then be made available to control speed limits in the those areas.

Countless other examples exist, however, from those provided above it can be seen that for the vehicle control system to function without error, certain types of information must be accurately provided. These include information permitting the vehicle to determine its absolute location and means for vehicles near each other to communicate this location information to each other. Additionally, map information that accurately provides boundary and lane information of the road must be available. Also, critical weather or road-condition information is necessary. The road location information need only be generated once and changed whenever the road geometry is altered. This information can be provided to the vehicle through a variety of techniques including prerecorded media such as CDROM or DVD disks or through communications from transmitters located in proximity to the vehicle, satellites, radio and cellular phones.

Consider now the case of the congested highway. Many roads in the world are congested and are located in areas where the cost of new road construction is prohibitive or such construction is environmentally unacceptable. It has been reported that an accident on such a highway typically ties up traffic for a period of approximately four times the time period required to clear the accident. Thus, by eliminating accidents, a substantial improvement in the congested highway problem results. This of course

is insufficient. On such highways each vehicle travels with a different spacing, frequently at different speeds and in the wrong lanes. If the proper spacing of the vehicles could be maintained, and if the risk of an accident could be substantially eliminated, vehicles under automatic control could travel at substantially higher velocities and in a more densely packed configuration thereby substantially improving the flow rate of vehicles on the highway by as much as a factor of 3 to 4 times. This not only will reduce congestion but also improve air pollution. Once again, if each vehicle knows exactly where it is located, can communicate its location to surrounding vehicles and knows precisely where the road is located, then the control system in each vehicle has sufficient information to accomplish this goal.

Again the intent of the system and process described here is to totally eliminate automobile accidents as well as reduce highway congestion. This process is to be designed to have no defective decisions. The process employs information from a variety of sources and utilizes that information to prevent accidents and to permit the maximum vehicle throughput on highways.

The information listed above is still insufficient. The geometry of a road or highway can be determined once and for all until erosion or construction alters the road. Properly equipped vehicles can know their location and transmit that information to other properly equipped vehicles. There remains a variety of objects whose location is not fixed, which have no transmitters and which can cause accidents. These objects include broken down vehicles, animals such as deer which wander onto highways, pedestrians, bicycles, objects which fall off of trucks, and especially other vehicles which are not equipped with location determining systems and transmitters for transmitting that information to other vehicles. Part of this problem can be solved for congested highways by restricting access to these highways to vehicles that are properly equipped. Also, these highways are typically in urban areas and access by animals can be effectively eliminated. Heavy fines can be imposed on vehicles that drop objects onto the highway. Finally, since every vehicle operator becomes part of the process, each such operator becomes a potential source of information to help prevent catastrophic results. Thus, each vehicle should also be equipped with a system of essentially stopping the process in an emergency. Such a system could be triggered by the operator strongly applying the brakes, rapidly turning the steering wheel or by activating a manual switch when the operator observes a critical situation but is not himself in immediate danger. An example of the latter case is where a driver witnesses a box falling off of a truck in an adjacent lane.

To solve the remaining problems, therefore, each vehicle should also be equipped with an anticipatory collision sensing system, or collision forecasting system, which is capable of identifying or predicting and reacting to a pending accident. As the number of vehicles equipped with the control system increases, the need for the collision forecasting system will diminish.

Once again, the operator will continue to control his vehicle provided he or she remains within certain constraints. These constraints are like a corridor.. As long as the operator maintains his vehicle within this allowed corridor, he or she can operate that vehicle without interference from the control system. That corridor may include the entire width of the highway when no other vehicles are present or it may be restricted to all East-bound lanes, for example. In still other cases, that corridor may be restricted to a single line and additionally, the operator may be required to keep his vehicle within a certain spacing tolerance from the preceding vehicle. If a vehicle operator wishes to exit a congested highway, he could

operate his turn signal that would inform the control system of this desire and permit the vehicle to safely exit from the highway. It can also inform other adjacent vehicles of the operator's intent, which could then automatically cause those vehicles to provide space for lane changing, for example. The highway control system is thus a network of individual vehicle control systems rather than a single highway resident computer system.

1.2 Limitations of the prior art

Previous inventions have attempted to solve the collision avoidance problem for each vehicle independently of the other vehicles on the roadway. Systems that predict vehicle trajectories fail because two vehicles can be on a collision course and within the last .1 second a slight change of direction avoids the collision. This is a common occurrence that depends on the actions of the individual drivers and no collision avoidance system now in existence can differentiate this case from an actual collision. In the present invention, every equipped vehicle will be confined to a corridor and to a position within that corridor where the corridor depends on sub-meter accurate digital maps. Only if that vehicle deviates from the corridor will an alarm sound or the vehicle control system take over control of the vehicle sufficiently to prevent the vehicle from leaving its corridor if an accident would result from the departure from that corridor.

Additionally, no prior art system has successfully used the GPS navigational system, or an augmented DGPS to locate a vehicle on a roadway with sufficient accuracy that that information can be used to prevent the equipped vehicle from leaving the roadway or striking another similarly equipped vehicle.

Prior art systems in addition to being poor at locating potential hazards on the roadway, have not been able to ascertain whether they are in fact on the roadway of off on the side, whether they are threatening vehicles, static signs over overpasses etc. In fact no credible attempt to date has been made to identify or categorize objects which may impact the subject vehicle.

The RtZF system also contemplates a different kind of interrogating system. It is based on scanning infrared laser radar with range gating. This system, when used in conjunction with accurate maps, will permit a precise imaging of an object on the road in front of the vehicle, for example, permitting it to be identified (using neural networks) and its location, velocity and the probability of a collision to be determined. This will be part of the Phase One IVI Program.

1.3 Summary and Objects of the invention

The first phase of this invention can be practiced with only minor retrofit type additions to the vehicle. These include the addition of a differential GPS system and an accurate map database. In this first phase the driver will only be warned when he or she is about to depart from the road surface. During the second phase of practicing this invention, the earning system will be augmented with a system which will prevent the operator from leaving the assigned corridor and in particular leaving the road at high speed. In further phases of the implementation of this invention, additional systems will be integrated which will scan the roadway and act to prevent accidents with vehicles that do not have the system installed. Also communication systems will be added to permit the subject vehicle to communicate its position, velocity etc. to other nearby vehicles which are also equipped with a system.

A primary preferred embodiment of the system, therefore, is to equip a vehicle with a DGPS system, an laser gyro inertial guidance system, vehicle steering and brake control apparatus, a sub-meter accurate digital map system with the relevant maps, a scanning sub-nanosecond pulsed infrared laser radar, a system for sensing or receiving signals from a highway based precise position determination system, and communications systems for (1) sending and receiving data from similarly equipped vehicles, (2) receiving updated maps and map status information, and (3) receiving weather and road condition information. A preferred embodiment for the infrastructure enhancements includes a DGPS system, a micropower impulse radar precise position determining system and local weather and road condition determination and transmission system.

This invention is a method and apparatus for preventing vehicle accidents. A vehicle is equipped with a differential GPS (DGPS) navigational system as well as an inertial navigation subsystem. Part of the system can be an array of infrastructure stations that permit the vehicle to exactly determine its position at various points along its path. Such stations would typically be located at intervals such as every 50 miles along the roadway, or more or less frequently depending on requirements as described below. These stations permit the vehicle to become its own DGPS station and thus to correct for the GPS errors and to set the position of the vehicle based initial guidance system. It also provides sufficient information for the vehicle to use the carrier frequency to determine its absolute position to within less than a meter. Data is also available to the vehicle that provides information as to the edges of the roadway at the location of the vehicle so that the vehicle control system can continuously determine its location relative to the roadway edges. In the initial implementation, the operator operates his or her vehicle and is unaware of the presence of the accident avoidance system. If, however, the operator falls asleep or for some other reason attempts to run off of the roadway at high speed, the system will detect that the vehicle is approaching an edge of the roadway and will either sound an alarm or prevent the vehicle from leaving the roadway when doing so would lead to an accident. In some cases the system will automatically reduce the speed of the vehicle and stop it on the shoulder of the roadway.

It is important to note that the invention as described in the above paragraph is in itself a significant improvement to automotive safety. Approximately half of all fatal accidents involve only a single vehicle that typically leaves the roadway and impacts with a roadside obstacle. This typically happens when the driver in under the influence of alcohol or drugs, has a medical emergency or simply falls asleep. If this cause of accidents could be eliminated, the potential exists for saving many thousands of deaths per year when all vehicles are equipped with the system of this invention. This would make this the single greatest advance in automotive safety surpassing both seatbelts and airbags in lifesaving potential.

A first improvement to the basic invention is to provide the vehicle with a means using radar, lidar, optical or infrared imaging, or a similar technology, to determine the presence, location and velocity of other vehicles on the roadway which are not equipped with the accident avoidance system. The accident avoidance system (RtZF™) of this invention will not be able to avoid all accidents with such vehicles for the reasons discussed above, but will be able to provide the level of protection at least equal to the prior art systems. Some improvement over prior art systems will result from the fact that the equipped vehicle knows the location of the roadway edges, as well as the lane boundaries, not only at the location of the

equipped vehicle but also at the location of the other nearby vehicles. Thus, the equipped vehicle will be able to determine that an adjacent vehicle has already left its corridor and warn the driver or initiate evasive action. In prior art systems, the location of the roadway is not known leading to significantly less discrimination ability.

A second improvement to the RtZF™ of this invention is to provide communication ability to other nearby similarly equipped vehicles permitting the continuous transmission and reception of the locations of all equipped vehicles in the vicinity. With each vehicle knowing the location, and thus the velocity, of all potential impacting vehicles which are equipped with the RtZF™, collisions between vehicles can be reduced and eventually nearly eliminated when all vehicles are equipped with the RtZF™.

A third improvement comprises the addition of software to the system that permits vehicles on especially designated vehicle corridors for the operator to relinquish control of the vehicle to the vehicle based system, and perhaps to a roadway computer system. This then permits vehicles to travel at high speeds in a close packed formation thereby substantially increasing the flow rate of vehicles on a given roadway. Naturally, in order to enter the designated corridors, a vehicle would be required to be equipped with the RtZF™. Similarly, this then provides an incentive to vehicle owners to have their vehicles so equipped so that they can enter the controlled corridors and thereby shorten their travel time.

Prior art systems require expensive modifications to highways to permit such controlled high speed close packed travel. Such modifications also require a substantial infrastructure to support the system. The RtZF™ of the present invention, in its simplest form, does not require any modification to the roadway but rather relies primarily on the GPS or similar satellite system. The edge and lane boundary information is either present within the vehicle RtZF™ memory or transmitted to the vehicle as it travels along the road. The permitted speed of travel is also communicated to the vehicles on the restricted corridor and thus each vehicle travels at the appointed speed. Since each vehicle knows the location of all other vehicles in the vicinity, should one vehicle slow down, due to an engine malfunction, for example, appropriate action can be taken to avoid an accident. Vehicles do not need to travel in groups as suggested and required by some prior art systems. Rather, each vehicle may independently enter the corridor and travel at the system defined speed until it leaves.

Another improvement involves the transmission of additional data concerning weather conditions, traffic accidents etc. to the equipped vehicle so that the speed of that vehicle can be limited to a safe speed depending on road conditions, for example. If moisture is present on the roadway and the temperature is dropping to the point that ice might be building up on the road surface, the vehicle can be notified by the roadway information system and prevented from traveling at an unsafe speed.

Principle objectives and advantages of the RtZF™ system of this invention include:

1. To provide a system based partially on the global positioning system (GPS) or equivalent that permits an onboard electronic system to determine the position of a vehicle with an accuracy of 1 meter or better.
2. To provide a system which permits an onboard electronic system to determine the position of the edges and/or lane boundaries of a roadway with an accuracy of 1 meter or less in the vicinity of the vehicle.

3. To provide a system which permits an onboard vehicle electronic system to determine the position of the edges and/or lane boundaries of a roadway relative to the vehicle with an accuracy of less than 2 meters.

4. To provide a system that substantially reduces the incidence of single vehicle accidents caused by the vehicle inappropriately leaving the roadway at high speed.

5. To provide a system which does not require modification to a roadway which permits high speed controlled travel of vehicles on the roadway thereby increasing the vehicle flow rate on congested roads.

6. To provide a collision avoidance system comprising a sensing system responsive to the presence of at least one other vehicle in the vicinity of the equipped vehicle and means to determine the location of the other vehicle relative to the lane boundaries of the roadway and thereby determine if the other vehicle has strayed from its proper position on the highway thereby increasing the risk of a collision. and taking appropriate action to reduce that risk.

7. To provide a means whereby vehicles near each other can communicate their position and/or their velocity to each other and thereby reduce the risk of a collision.

8. To provide a means for accurate maps of a roadway can be transmitted to a vehicle on the roadway.

9. To provide a means for weather. road condition and/or similar information can be communicated to a vehicle traveling on a roadway plus means within the vehicle for using that information to reduce the risk of an accident.

10. To provide a means and apparatus for a vehicle to precisely know its location at certain positions on a road by passing through or over an infrastructure based local subsystem thereby permitting the vehicle electronic systems to self correct for the satellite errors making the vehicle for a brief period its own DGPS station.

11. To utilize government operated navigation aid systems such as the WAAS and LARS as well as other available or to become available systems to achieve sub-meter vehicle location accuracies.

12. To utilize the OpenGIS™ map database structure so as to promote open systems for accurate maps for the RtZF™ system.

In contrast to some prior art systems, with the RtZF™ system of this invention, especially when all vehicles are appropriately equipped, automatic braking of the vehicle should rarely be necessary and steering and engine control should in most cases be sufficient to prevent accidents. In most cases, braking means the accident wasn't anticipated.

It is important to understand that this is a process control problem. The process is designed so that it should not fail and thus all accidents should be eliminated. Events that are troublesome to the system include a deer running in front of the vehicle, a box falling off of a truck, a rock rolling onto the roadway and a catastrophic failure of a vehicle. Continuous improvement to the process is thus required before these events are substantially eliminated. Each individual driver is part of the system and upon observing that such an event has occurred he or she should have the option of stopping the process to prevent or mitigate an emergency. All equipped vehicles therefore have the capability of communicating that the

process is stopped and therefore that the vehicle speed, for example, should be substantially reduced until the vehicle has passed the troubled spot or until the problem ceases to exist. In other words, each driver is part of the process.

The RtZF™ system of this invention will thus start simple by reducing single vehicle accidents and evolve. The system has the capability to solve the entire problem by eliminating automobile accidents.

This invention is a method and apparatus for eliminating accidents by accurately determining the position of a vehicle, accurately knowing the position of the road and communicating between vehicles and vehicle and the infrastructure. People get into accidents when they go too fast for the conditions and when they get out of their corridor. This invention eliminates these and other causes of accidents. In multilane highways, this system prevents people from shifting lanes if there are other vehicles in the blind spot, thus, solving the blind spot problem. The vehicle would always be traveling down a corridor where the width of the corridor may be a lane or the entire road width or something in between depending on road conditions and the presence of other vehicles.

The invention is implemented through the use of both an inertial navigation system (INS) and a DGPS, ion some cases with carrier frequency enhancement. Due to the fact that the signals from at least four GPS or GLONASS satellites are not always available and to errors caused by multiple path reception from a given satellite, the DGPS systems cannot be totally relied upon. Therefore the INS is a critical part of the system. This will improve as more satellites are launched and additional ground stations are added. It will also significantly improve when the WAAS system in implemented and refined to work with land vehicles as well as airplanes.

Other improvements will now be obvious to those skilled in the art. The above features are meant to be illustrative and not definitive.

1.4 Brief review of the drawings

Fig. 1 illustrates the GPS satellite system with the 24 satellites revolving around the earth.

Fig. 2 illustrates four such satellites and a pseudolite transmitting position information to a vehicle and to a base station which in turn transmits the differential correction signal to the vehicle.

Fig. 3 is a logic diagram showing the combination of the GPS system and an inertial navigation system.

Fig. 4 illustrates a vehicle traveling on a roadway in a defined corridor.

Fig. 5 illustrated two adjacent vehicles traveling on a roadway and communicating with each other.

Fig. 6 illustrates the use of three micropower impulse radar transmitters in a configuration to allow a vehicle to accurately determine its position.

Fig. 7 is a schematic illustration of the system in accordance with the invention.

Fig. 8 is a flow chart of the method in accordance with the invention.

2. Description of GPS system

2.1 Background of GPS

Referring to Fig. 1, the presently implemented Global Positioning System with its constellation of 24 satellites 102 is truly revolutionizing navigation throughout the world. The satellites orbit the Earth in

six orbits 104. However, in order to reach its full potential for airline navigation, GPS needs to be augmented both to improve accuracy and to reduce the time needed to inform an aircraft pilot of a malfunction of a GPS satellite, the so-called integrity problem.

The Global Positioning System (GPS) is a satellite-based navigation and time transfer system developed by the U.S. Department of Defense. GPS serves marine, airborne and terrestrial users, both military and civilian. Specifically, GPS includes the Standard Positioning Service (SPS) that provides civilian users with 100 meter accuracy as to the location or position of the user. It also serves military users with the Precise Positioning Service (PPS) which provides 20 meter accuracy for the user. Both of these services are available worldwide with no requirement for any local equipment.

Differential operation of GPS is used to improve the accuracy and integrity of GPS. Differential GPS places one or more high quality GPS receivers at known surveyed locations to monitor the received GPS signals. This reference station(s) estimates the slowly varying components of the satellite range measurements, and forms a correction for each GPS satellite in view. The correction is broadcast to all DGPS users within the coverage area of the broadcast facilities.

For a good discussion of DGPS, for following paragraphs are reproduced from OMNISTAR:

The new OMNISTAR Model 6300A offers unprecedented versatility for portable, real-time, DGPS positioning. It can improve the accuracy of a GPS receiver by as much as 100 times. If your product or service needs precise positioning information, then chances are good that OMNISTAR can supply that need; and at a reasonable cost.

OMNISTAR is a Differential GPS (DGPS)System. It is capable of improving regular GPS to sub-meter accuracy. GPS computes a user's position by measuring ranges (actually, pseudoranges; which are ranges that are calculated by an iterative process) to three or more GPS satellites simultaneously. The Department of Defense (DOD) is intentionally limiting the accuracy of the calculation by continuously changing the onboard clock on the satellites. This process is called Selective Availability, or "SA". This appears as a continuous variation in the user's position. Using GPS in an uncorrected (stand-alone) mode, a user's calculated position will continuously move around the true position in a near-random pattern. The indicated position may move out as far as 100 meters from the true position. The randomness makes it impossible to predict. If a user samples the position data over a long period of time, such as 24 hours, the average or mean will likely be within a meter of the true position. In statistical terms, the standard deviation will be approximately 15 to 20 meters in each horizontal coordinate.

A DGPS System generates corrections for SA and other errors. This is accomplished by the use of one or more GPS "Base Stations" that measure the errors in the GPS system and generate corrections. A "real-time" DGPS System not only generates the corrections, but provides some methodology for getting those corrections to users as quickly as possible. This always involves some type of radio transmission system. They may use microwave systems for short ranges, low frequencies for medium ranges and geostationary satellites for coverage of entire continents.

The method of generating corrections is similar in most DGPS systems. A GPS base station tracks all GPS Satellites that are in view at its location. The internal processor knows the precise surveyed location of the base station antenna, and it can calculate the location in space of all GPS satellites at any time by using the epheremis that is a part of the normal broadcast message from all GPS satellites. From these two pieces of information, an

expected range to each satellite can be computed at any time. The difference between that computed range and the measured range is the range error. If that information can quickly be transmitted to other nearby users, they can use those values as corrections to their own measured GPS ranges to the same satellites. The key word is "quickly", because of the rapid change in the SA errors. In most radio systems, bandwidth is a finite limitation which dictates how much data can be sent in a given time period. That limitation can be eased somewhat by having the GPS base station software calculate the rate of change of the errors and add that information as part of the correction message. That term is called the range rate value and it is calculated and sent along with the range correction term. The range correction is an absolute value, in meters, for a given satellite at a given time of day. The range rate term is the rate that correction is changing, in meters per second. That allows GPS user sets to continue to use the "correction, plus the rate-of-change" for some period of time while it's waiting for a new message. The length of time you can continue to use that data without an update depends on how well the range rate was estimated. In practice, it appears that OMNISTAR would allow about 12 seconds before the DGPS error would cause a one meter position error. In other words, the "age of data" can be up to 12 seconds before the error from that term would cause a one meter position error. OMNISTAR transmits a new correction message every two and one/half seconds, so even if an occasional message is missed, the user's "age of data" is still well below 12 seconds.

The OMNISTAR DGPS System was designed with the following objectives: (1) continental coverage; (2) sub-meter accuracy over the entire coverage area; and (3) a portable system (backpack). The first objective dictated that the transmission system had to be from a geostationary satellite. We purchased a transponder on satellite Spacenet 3, which is located at 87 degrees West longitude. It has an antenna pattern that covers most of North America; specifically, all of the 48 states, the northern half of Mexico and the southern half of Canada. It also has sufficient power within that footprint that a tiny omnidirectional antenna can be used at the user's receiver.

The methodology developed by John E. Chance & Assoc. of using multiple GPS base stations in a user's solution and reducing errors due to the GPS signal traveling through the atmosphere, met the second objective. It was the first widespread use of a "Wide Area DGPS Solution". It is able to use data from a relatively small number of base stations and provide consistent accuracy over extreme distances. A unique method of solving for atmospheric delays and weighting of distant base stations, achieves sub-meter capability over the entire coverage area - regardless of the user's proximity to any base station. This achieves a truly nationwide system with consistent characteristics. A user can take the equipment anywhere within the coverage area and get consistent results, without any intervention or intimate knowledge of GPS or DGPS.

The units being sold today are sufficiently portable that they can used in a backpack. They can include an internal GPS engine (optional) that will provide a complete solution in a single system package. All that is needed is a data collector or notebook computer for display and storage of corrected GPS data.

The OMNISTAR Network consists of ten permanent base stations that are scattered throughout the Continental US, plus one in Mexico. These stations track all GPS Satellites above 5 degrees elevation and compute corrections every 600 milliseconds. The corrections are in the form of an industry standard message format called RTCM-104, Version II. The corrections are sent to the OMNISTAR Network Control Center in Houston via lease lines, with a dial back-up. At the NCC these messages are checked, compressed, and formed into a packet for transmission up to our satellite transponder. This occurs approximately every 2 to 3 seconds. A packet will contain the latest data from each of the 11 base stations.

All OMNISTAR user sets receive these packets of data from the satellite transponder. The messages are first decoded from the spread-spectrum transmission format and then uncompressed. At that point, the message is an exact duplicate of the data as it was generated at each base station. Next, the atmospheric errors must be corrected. Every base station automatically corrects for atmospheric errors at it's location; but the user is not at any of those locations, so the corrections are not optimized for the user - and, OMNISTAR has no information as to each individual's location. If these errors are to be optimized for each user, then it must be done in each user's OMNISTAR. For this reason, each OMNISTAR user set must be given an approximation of its location. The approximation only needs to be within 50 to 100 miles of its true position. Given that information, the OMNISTAR user set can remove most of the atmospheric correction from each Base Station message and substitute a correction for his own location. In spite of the loose approximation of the user's location, this information is crucial to the OMNISTAR process. It makes the operation totally automatic and it is necessary for sub-meter positioning. If it is totally ignored, errors of up to ten meters can result.

Fortunately, this requirement of giving the user's OMNISTAR an approximate location is easily solved. If OMNISTAR is purchased with the optional internal GPS receiver installed, the problem is taken care of automatically by using the position output of the GPS receiver as the approximation. It is wired internally to do exactly that. An alternate method - when the internal GPS receiver is not present - is to use the user's external GPS receiver for this function. In that case, the user's receiver must have an output message in one of the approved formats (NMEA) and protocols that OMNISTAR can recognize.

That output can be connected back to the OMNISTAR set by using the same cable that normally supplies the RTCM-104 from OMNISTAR to the user's GPS receiver. This method works perfectly well when all the requirements on format and protocol are met. There is a third method, where a user uses a notebook computer to type in an estimated location into the OMNISTAR user set. Any location entered by this method is preserved - with an internal battery - until it is changed. This method works fine where the user does not intend to go more than 50-100 miles from some central location.

After the OMNISTAR processor has taken care of the atmospheric corrections, it then uses it's location versus the eleven base station locations, in an inverse distance-weighted least-squares solution. The output of that least-squares calculation is a synthesized RTCM-104 Correction Message that is optimized for the user's location. It is always optimized for the user's location that is input from the user's GPS receiver or as an approximation that is typed in from a notebook computer. This technique is called the "Virtual Base Station Solution". It is this technique that enables the OMNISTAR user to operate independently and consistently over the entire coverage area without regard to where he is in relation to our base stations. As far as we have determined, users are obtaining the predicted accuracy over the entire area."

The above description is provided to illustrate the accuracy which can be obtained from the DGPS system. It is expected that the WAAS system when fully implemented will provide the same benefits as provided by the OMNISTAR system. However, when the standard deviation of approximately .5 meter is considered, it is evident that this WAAS system is insufficient by itself and will have to be augmented by other systems to improve the accuracy.

GLONASS is a Russian system similar to GPS. This system provides accuracy that is better than GPS with SA on and not as good as GPS with SA off. It is expected that SA will be removed before the system described herein is implemented.

The Projected Position Accuracy of GPS and GLONASS, Based on the Current Performance is:

	Horizontal Error (m)		Vertical Error (m)
	(50%)	(95%)	(95%)
GPS (SA off)	7	18	34
GPS (SA on)	27	72	135
GLONASS	10	26	45
GPS+GLONASS 9	20		38

The system described here will achieve a higher accuracy than reported in the above table due to the combination of the inertial guidance system that permits accurate changes in position to be determined and through multiple GPS readings. In other words, the calculated position will converge to the real position over time. The addition of DGPS will provide an accuracy improvement of at least a factor of 10, which, with the addition of a sufficient number of pseudolite and DGPS stations in some cases is sufficient without the use of the carrier frequency correction. A further refinement where the vehicle becomes its own DGPS station through the placement of infrastructure stations at appropriate locations on roadways will further significantly enhance the system accuracy to the required level.

Multipath is the situation where more than one signal from a satellite comes to a receiver with one of the signals resulting from a reflection off of a building or the ground, for example. Since multipath is a function of geometry, the system can be designed to eliminate its effects based on highway surveying and appropriate antenna design. Multipath from other vehicles can also be eliminated since the location of the other vehicles will be known.

2.2 DGPS

As discussed below, the Wide Area Augmentation System (WAAS) is being installed by the US Government to provide DGPS for airplane landings. The intent is to cover the entire continental U.S. (CONUS). This may be useful for much of the country for the purposes of this invention. Another alternative would be to use the cellular phone towers, since there are so many of them, if they could be programmed to act as pseudolites.

An important feature of DGPS is that the errors from the GPS satellites change slowly with time and therefore, only the corrections need be sent to the user from time to time. Using reference receivers separated by 25-120 km, accuracies from 10 cm to 1 m are achievable using DGPS which is marginal for RtZF™. Alternately, through the placement of appropriate infrastructure transmitters as described below even better accuracies are obtainable.

A type of wide area DGPS system has been developed spans the entire US continent which provides position RMS accuracy to better than 50 cm. This system is described in the Bertiger, et al, "A Prototype Real-Time Wide Area Differential GPS System," Proceedings of the National Technical Meeting, Navigation and Positioning in the Information Age, Institute of Navigation, January 14-16, 1997 pp. 645-655. A RMS error of 50 cm would be marginally accurate for RtZF™. Many of the teachings of

this invention especially if the road edge and lane location error were much less which could be accomplished using more accurate surveying equipment.

A similar DGPS system which is now being implemented on a nationwide basis is described in " "DGPS Architecture Based on Separating Error Components, Virtual Reference Stations and FM Subcarrier Broadcast", by Differential Corrections Inc., 10121 Miller Ave., Cupertino, CA 95041. The system described in this paper promises an accuracy on the order of 10 cm.

Suggested DGPS update rates are usually less than twenty seconds. DGPS removes common-mode errors, those errors common to both the reference and remote receivers (not multipath or receiver noise). Errors are more often common when receivers are close together (less than 100 km). Differential position accuracies of 1-10 meters are possible with DGPS based on C/A code SPS signals.

Using the Cnet commercial system, 1 foot accuracies are possible if base stations are no more than 30 miles from the vehicle unit. This would require approximately 1000 base stations to cover CONUS. Alternately, the same accuracy is obtainable if the vehicle can become its own DGPS system every 30 miles as described below.

Unfortunately, the respective error sources mentioned above rapidly decorrelate as the distances between the reference station and the vehicle increases. Conventional DGPS is the terminology used when the separation distances are sufficiently small that the errors cancel. The terms single-reference and multi-reference DGPS are occasionally used in order to emphasize whether there is a single reference station or whether there are multiple ones. If it is desired to increase the area of coverage and, at the same time, to minimize the number of fixed reference receivers, it becomes necessary to model the spatial and temporal variations of the residual errors. Wide Area Differential GPS (WADGPS) is designed to accomplish this. In addition, funds have now been appropriated for the US Government to deploy a national DGPS system.

2.3 Pseudolites

Pseudolites are artificial satellite like structures, can be deployed to enhance the accuracy of the DGPS system. Such structures could become part of the RtZF™ system.

2.4 WAAS

The Wide Area Augmentation System (WAAS) is being deployed to replace the Instrument Landing System used at airports across the country. The WAAS system provides an accuracy of from 1 to 2 meters for the purpose of aircraft landing. If the vertical position of the vehicle is known, as would be in the case of automobiles at a known position on a road, this accuracy can be improved significantly. Thus, for many of the purposes of this invention, the WAAS can be used to provide accurate positioning information for vehicles on roadways. The accuracy of the WAAS is also enhanced by the fact that there is an atomic clock in every WAAS receiver station that would be available to provide great accuracy using carrier phase data. With this system sub-meter accuracies are possible for some locations.

The WAAS is based on a network of approximately 35 ground reference stations. Signals from GPS satellites are received by aircraft receivers as well as by ground reference stations. Each of these reference stations is precisely surveyed, enabling each to determine any error in the GPS signals being received at its own location. This information is then passed to a wide area master station. The master station calculates correction algorithms and assesses the integrity of the system. This data is then put into a

message format and sent to a ground earth station for uplink to a geostationary communications satellite. The corrective information is forwarded to the receiver on board the aircraft, which makes the needed adjustments. The communications satellites also act as additional navigation satellites for the aircraft, thus, providing additional navigation signals for position determination.

This system will not meet all of FAA's requirements. For category III landings, the requirement is 1.6-m vertical and horizontal accuracy. To achieve this, FAA is planning to implement a network of local area differential GPS stations that will provide the information to aircraft. This system is referred to as the Local Area Augmentation System (LAAS).

The WAAS system, which consists of a network of earth stations and geo-synchronous satellites, is currently being funded by the U.S. Government for aircraft landing purposes. Since the number of people that die yearly in automobile accidents greatly exceeds those killed in airplane accidents, there is clearly a greater need for a WAAS type system for solving the automobile safety problem using the teachings of this invention. Also, the reduction in required highway funding resulting from the full implementation of this invention would more then pay for the extension and tailoring of the WAAS to cover the nations highways.

2.5 LAAS

The Local Area Augmented System (LAAS) is also being deployed in addition to the WAAS system to provide even greater coverage for the areas surrounding major airports. According to Newsletter of the Institute of Navigation, 1997, "the FAA's schedule for (LAAS) for Category II and III precision instrument approaches calls for development of standards by 1998 that will be sufficient to complete a prototype system by 2001. The next step will be to work out standards for an operational system to be fielded in about 2005, that could serve nationwide up to about 200 runways for Cat II-III approaches."

In a country like the United States, which has many airfields, a WAAS can serve a large market and is perhaps most effective for the control of airplane landings. The best way for other countries, with fewer airports, to participate in the emerging field of GPS-based aviation aids may be to build LAAS. In countries with a limited number of airports, LAAS is not very expensive while the costs of building a WAAS to get Category I type accuracy is very expensive. However, with the added benefit of less highway construction and greater automobile safety, the added costs for a WAAS system may well be justified for much of the world.

For the purposes of the RtZF™ system, both the WAAS and LAAS would be useful but probably insufficient. Unlike an airplane, there are many places where it might not be possible to receive LAAS and WAAS information or even more importantly the GPS signals themselves with sufficient accuracy and reliability. Initial RtZF™ systems may therefore rely on the WAAS and LAAS but as the system develops more toward the goal of zero fatalities road based systems which permit a vehicle to pinpoint its location are preferred. However, there is considerable development ongoing in this field so that all systems are still candidates for use with RtZF™ and only time will determine which are the most cost effective.

2.6 Carrier Phase Measurements

An extremely accurate form of GPS is Carrier Based Differential GPS. This form of GPS utilizes the 1.575 GHz carrier component of the GPS signal on which the Pseudo Random Number (PRN) code and

the data component are superimposed. Current versions of Carrier Based Differential GPS involve generating position determinations based on the measured phase differences at two different antennas, a base station or pseudolite and the vehicle, for the carrier component of a GPS signal. This technique initially requires determining how many integer wave-lengths of the carrier component exist between the two antennas at a particular point in time. This is called integer ambiguity resolution. A number of approaches currently exist for integer ambiguity resolution. Some examples can be found in U.S. Patents 5,583,513 and 5,619,212. Such systems can achieve sub-meter accuracies and, in some cases, accuracies of 1 cm. U.S. Pat. 5,477,458 discloses a DGPS system that is accurate to 5 cm with the base stations located on a radius of 3000 km. With such a system, very few base stations would be required to cover the continental United States. This system still suffers from the availability of accurate signals at the vehicle regardless of its location on the roadway and the location of surrounding vehicles and objects. Nevertheless, the principle of using the carrier frequency to precisely determine the location of a vehicle can be used with the highway based systems described below to provide extreme location accuracies. Using the system described below where a vehicle becomes its own DGPS system, the carrier phase ambiguity problem also disappears.

2.7 Other Aids

There are other sources of information that can be added to increase the accuracy of position determination. The use of GPS with four satellites provides the three dimension location of the vehicle plus time. Of the dimensions, the vertical is the least accurately known, yet, if the vehicle knows where it is on the roadway, the vertical dimension is not only the least important but it is also already accurately known from the roadmap information plus the inertial guidance system.

Another aid is to provide markers along side the roadway which can be either visual, passive or active transponders, reflectors, or a variety of other technologies, which have the property that as a vehicle passes the marker, it can determine the identity of the marker and from a data base it can determine the exact location of the marker. If three or more of such markers are placed along side of the roadway, a passing vehicle can determine its exact location by triangulation. Although it may be impractical to initially place such markers along all roadways, it would be reasonable to place them in particularly congested areas or places where it is known that a view of one or more of the GPS satellites is blocked. A variation of this concept will be discussed below.

Although initially it is preferred to use the GPS navigational satellites as the base technology, the invention is not limited thereby and contemplates using all methods by which the location of the vehicle can be accurately determined relative to the earth surface. The location of the roadway boundaries and the location of other vehicles relative to the earth surface are also to be determined and all relevant information used in a control system to substantially reduce and eventually eliminate vehicle accidents. Only time and continued system development will determine the mix of technologies that provide the most cost effective solution. All forms of information and methods of communication to the vehicle are contemplated including direct communication with stationary and moving satellites, communication with fixed earth based stations using infrared, optical, radar, radio and other segments of the electromagnetic spectrum. Some additional examples follow:

A pseudo-GPS can be delivered from cell phone stations, in place of or in addition to satellites. DGPS corrections can be communicated to a vehicle via FM radio via a sub-carrier frequency for example. An infrared or radar transmitter along the highway can transmit road boundary location information. A CD-ROM or other portable mass storage can be used at the beginning of a controlled highway to provide road boundary information to the vehicle. Finally, it is contemplated that eventually a satellite will broadcast periodically, perhaps every five minutes, a table of dates covering the entire CONUS that provides the latest update date of each map segment. If a particular vehicle does not have the latest information for a particular region where it is operating, it will be able to use its cell phone to call and retrieve such road maps perhaps through the Internet. Emergency information would also be handled in a similar manner so that if a tree fell across the highway, all nearby vehicles would be notified.

2.8 Other Location Fixing Systems

It is expected, especially initially, that there will be many holes in the DGPS or GPS and their various implementations that will leave the vehicle without an accurate means of determining its location. The inertial navigation system described below will help in filling these holes but its accuracy is limited to a time period significantly less than an hour and a distance of less than 50 miles before it needs correcting. That may not be sufficient to cover the period between DGPS availability. It is therefore contemplated that the RtZF™ system will also make use of low cost systems located along the roadways that permit a vehicle to accurately determine its location. One example of such a system would be to use a group of three Micropower Impulse Radar (MIR) units such as developed by Lawrence Livermore Laboratory.

A MIR operates on very low power and periodically transmits a very short spread spectrum radar pulse. The estimated cost of a MIR is less than $10 even in small quantities. If three such MIRs, 51, 52 and 53, as shown in FIG. 6, are placed along the highway and triggered simultaneously, and if a vehicle has an appropriate receiver system, the time of arrival of the pulses can be determined and thus the location of the vehicle relative to the transmitters determined. The exact location of the point where all three pulses arrive simultaneously would be the point that is equal distant from the three transmitters and would be located on the map information. Thus it would not even be necessary to have the signals contain identification information since the vehicle would not be so far off in its position determination system to confuse different locations. By this method, the vehicle would know exactly where it was whenever it approached and passed such a triple-MIR installation.

Naturally, several such readings and position determinations can be made with one approach to the MIR installation, the vehicle need not wait until they all arrive simultaneously. Also the system can be designed so that the signals never arrive at the same time and still provide the same accuracy as long as there was a sufficiently accurate clock on board. One way at looking at FIG.6 is that transmitters 51 and 52 fix the lateral position of the vehicle while transmitters 51 and 53 fix the location of the vehicle longitudinally. The three transmitters need not be along the edges on one lane but could span multiple lanes and they need not be at ground level but could be placed sufficiently in the air so that passing trucks would not block the path of the radiation from an automobile. Particularly in congested areas it might be desirable to code the pulses and to provide more than three transmitters to further protect against signal blockage or multipath.

The power requirements for the MIR are sufficiently low that a simple photoelectric cell array can provide sufficient power for most if not all CONUS locations. With this exact location information, the vehicle can become its own DGPS station and determine the corrections necessary for the GPS. It can also determine the integer ambiguity problem and thereby know the exact number of wave lengths between the vehicle and the satellites or the vehicle and the last MIR installation.

MIR is one of several technologies that can be used to provide precise location determination. Others include the use of an RFID tag that is designed in cooperation with its interrogator to provide a distance to the tag measurement and radar or other reflectors where the time of flight can be measured.

Once a vehicle passes a precise positioning station such as the MIR triad described above, the vehicle can communicate this information to surrounding vehicles. If the separation distance between two communicating vehicles can also be determined by some type of time-of-flight method, then the vehicle that has just passed the triad can, in effect, become a satellite equivalent or moving pseudolite. This then begins the process of eventually eliminating the dependence on the GPS satellites. Finally, if many vehicles are communicating their positions to many other vehicles along with an accuracy of position assessment, each vehicle can use this information along with the measured separation distances to improve the accuracy that its position in known. In this manner as the number of such vehicles increases the accuracy of the whole system increases and dependence on the GPS satellites decreases until an extremely accurate positioning system for all vehicles results. Such a system since in combines many sources of position information is tolerant of the failure of any one or even several such sources. Thus, the RtZF™ system becomes analogous to the Internet in that it can't be shut down and the goal of perfection is approached. Some of the problems associated with this concept will be discussed in more detail below.

2.9 Inertial Navigation System

In many cases, especially before the system implementation becomes mature and the complete infrastructure is in place, there will be times when the system is not operational. This could be due to obstructions hiding a clear view of a sufficient number of GPS satellites, such as when a vehicle enters a tunnel. It could also be due to a lack of road boundary information, due to construction or the fact that the road has not been surveyed and the information recorded and made available to the vehicle, or a variety of other causes. It is contemplated, therefore, that each equipped vehicle will contain a warning light that warns the driver when he is at a position where the system is not operational. If this occurs on one of the especially designated highway lanes, the vehicle speed will then also be reduced until the system again becomes operational.

When the system is non-operational for a short distance, the vehicle will still accurately know its position if there is in addition a laser gyroscope, micromachined angular rate sensor or equivalent, and some other velocity or position measuring system which together is referred to as an Inertial Navigation System (INS).

In implementations where control of the vehicle steering is assumed by the system at least to the extent that the vehicle is prevented from leaving its assigned corridor, the vehicle should also have a yaw rate sensor rather than relying on a steering wheel angle sensor which can be less accurate.

As more sensors which are capable of providing information on the vehicle position. velocity and acceleration are added onto the vehicle. the system can become sufficiently complicated as to require a neural network system to permit the optimum usage of the available information. This becomes even more important when information from outside the vehicle other than the GPS related systems becomes more and more available. For example. a vehicle may be able to communicate with other vehicles that have similar systems and learn their estimated location. If the vehicle can independently measure the position of the other vehicle. for example through the use of the scanning impulse laser radar system described below. and thereby determine the relative position of the two or more vehicles. a further improvement of the position can be determined for all such vehicles. Adding all such additional information into the system would probably require a computational method such as neural networks or a combination of a neural network and a fuzzy logic system.

2.10 Conclusion - How Used

One way to imagine the system operation is to consider each car and roadway edge to behave as if it had a surrounding "force field" that would prevent it from crashing into another vehicle or an obstacle along the roadway. A vehicle operator would be prevented from causing his or her vehicle to leave its assigned corridor. This is accomplished with a control system that controls the steering. acceleration and perhaps the vehicle brakes based on its knowledge of the location of the vehicle. highway boundaries and other nearby vehicles. In a preferred implementation. the location of the vehicle is determined by first using the GPS L1 signal to determine its location within approximately 100 meters. Then using DGPS and corrections which are broadcast whether by FM or downloaded from geo-synchronous or Low Earth Orbiting (LEO) satellites or obtained from road based transmitters to determine its location within less than 10 centimeters. Finally the use of a MIR or similar system periodically permits the vehicle to determine its exact location and thereby determine the GPS corrections. eliminate the carrier cycle ambiguity and set the INS system. If this is still not sufficient. then the phase of the carrier frequency provides the required location information to a few centimeters. Dead reckoning. using vehicle speed. steering angle and tire rotation information and/or inertial guidance. is used to fill in the gaps. Where satellites are out of view, pseudolites. or other systems. are placed along the highway. A pulsed scanning infrared laser radar system. or an equivalent system. is used for near obstacle detection. Communication to other vehicles is by short distance radio or by spread spectrum time domain pulse radar as described by Time Domain Incorporated.

One problem which will require addressing as the system becomes mature is satellite temporary blockage by large trucks or other movable objects whose location cannot be foreseen by the system designers. Another concern is to prevent vehicle owners from placing items on the vehicle exterior that block the GPS and communication antennas.

3. Communication with other vehicles - Collision Avoidance

MIR might also be used for Vehicle to vehicle communication except that it is line of sight. An advantage is that we can know when a particular vehicle will respond by range gating. Also the short time of transmission permits many vehicles to communicate at the same time

3.1 Description - Requirements

The communication between vehicles for collision avoidance purposes cannot solely be based on line-of-sight technologies as this is not sufficient since vehicles which are out of sight can still cause accidents. On the other hand, vehicles that are a mile away but still in sight need not be part of the communication system. Messages sent by each vehicle of the subject invention would contain information indicating exactly where it is located and perhaps information as to what type of vehicle it is. The subject vehicle can therefore eliminate all of those vehicles that are not potential threats, even if such vehicles are very close, but on the other side of the highway barrier.

The use of an Ethernet protocol will satisfy the needs of the network, which would consist of all threatening vehicles in the vicinity of the subject vehicle. Alternately, a network where the subject vehicle transmits a message to a particular vehicle and waits for a response could be used. From the response time, the relative position of other vehicles can be ascertained which provides one more method of position determination. Thus, the more vehicles that are on the road with the equipped system, the greater accuracy of the overall system and thus the safer the system becomes as described above.

To prevent accidents caused by a vehicle leaving the road surface and impacting a roadside obstacle requires only an accurate knowledge of the position of the vehicle and the road boundaries. To prevent collisions with other vehicles requires that the position of all nearby automobiles must be updated continuously. But just knowing the position of a threatening vehicle is insufficient. The velocity, size and orientation of the vehicle is also important in determining what defensive action may be required. Once all vehicles are equipped with the system of this invention, the communication of all relevant information will take place via a radio communication link. In addition to signaling its absolute position, each vehicle will send a message identifying the approximate mass, velocity, orientation, and other relevant information. This has the added benefit that emergency vehicles can make themselves known to all vehicles in their vicinity and all such vehicles can then take the appropriate action. The same system can also be used to relay accident or other hazard information from vehicle to vehicle.

3.2 Preferred System

One preferred method of communication between vehicles uses that portion of the electromagnetic spectrum that permits only line of sight communication. In this manner, only those vehicles that are in view can communicate. In most cases, a collision can only occur between vehicles that can see each other. This system has the advantage that the "communications network" only contains nearby vehicles. This would require that when a truck, for example, blocks another stalled vehicle that the information from the stalled vehicle be transmitted via the truck to a following vehicle. An improvement in this system would use a rotating aperture that would only allow communication from a limited angle at a time further reducing the chance for multiple messages to interfere with each other. Each vehicle transmits at all angles but receives at only one angle at a time. This has the additional advantage of confirming at least the direction of the transmitting vehicle. An infrared rotating receiver can be looked at as similar to the human eye. That is, it is sensitive to radiation from a range of directions and then focuses in on the particular direction, one at a time, from which the radiation is coming. It needn't scan continuously. In fact the same transmitter which transmits 360 degrees could also receive from 360 degrees with the scanning done in software.

A alternate preferred method is to use short distance radio communication so that a vehicle can receive position information from all nearby vehicles such as the DS/SS system. The location information received from each vehicle can then be used to eliminate it from further monitoring if it is on a different roadway or not in a potential path of the subject vehicle.

Many communications schemes have been proposed for inter-vehicle and vehicle to road communication. At this time the suggested approach utilizes DS/SS communications in the 2.4 GHz INS band. Experiments have shown that communications are 100 percent accurate at distances up to 200 meters. At a closing velocity of 200 KPH, at .5 g deceleration, it requires 30 meters for a vehicle to stop. Thus, communication accurate to 200 meters is sufficient to cover all vehicles that are threatening to a particular vehicle.

A related method would be to use a MIR system in a communications mode. Since the width of the pulses typically used by MIR is less than a nanosecond, many vehicles can transmit simultaneously without fear of interference.

With either system, other than the MIR system, the potential exists that more than one vehicle will attempt to send a communication at the same time and there will then be a data collision. If all of the communicating vehicles are considered as being part of a local area network, the standard Ethernet protocol can be used to solve this problem. In that protocol, when a data collision occurs, each of the transmitting vehicles which was transmitting at the time of the data collision would be notified that a data collision had occurred and that they should retransmit their message at a random time later. When several vehicles are in the vicinity and there is the possibility of collisions of the data, each vehicle can retain the coordinates last received from the surrounding vehicles as well as their velocities and predict their new locations even though some data was lost.

If a line of sight system were used, an infrared or MIR system would be good choices. In the infrared case, and if an infrared system were also used to interrogate the environment for non-equipped vehicles, pedestrians, animals etc., as will be discussed below, both systems could use some of the same hardware.

If point to point communication can be established between vehicles, such as described in U.S. Pat. 5,528,391 to Elrod, then the need for a collision detection system like Ethernet would not be required. If the receiver on a vehicle, for example, only has to listen to one sender from one other vehicle at a time, then the bandwidth can be considerably higher since there will not be any interruption.

When two vehicles are communicating their positions to each other, it is possible through the use of range gating or the sending of a clear to send signal and timing the response to determine the seperation of the vehicles. This assumes that the properties of the path between the vehicles in know which would be the case if the vehicles are within view of each other. If, on the other hand, there is a row of trees between the two vehicles, a false distance measurement would be obtained if the radio waves pass through a tree. If the communication frequency is low enough that it can pass through a tree in the above example it will be delayed. If it is a much higher frequency such that is blocked by the tree then it still might reach the second vehicle through a multi-path. Thus, in both cases an undetectable range error results. If a range of frequencies is sent as in a spread spectrum and the first arriving pulse contains all of the sent frequencies

then it is likely that the two vehicles are in view of each other and the range calculation is accurate. If any of the frequencies are delayed then the range calculation can be considered inaccurate and should be ignored.

3.3 Enhancements

In the accident avoidance system of the present invention, the information indicative of a collision could come from a vehicle that is quite far away from the closest vehicles to the subject vehicle. This is a substantial improvement over the prior art collision avoidance systems, which can only react to a few vehicles in the immediate vicinity. The system described herein also permits better simultaneous tracking of several vehicles. For example, if there is a pileup of vehicles down the highway then this information can be transmitted to control other vehicles that are still a significant distance from the accident. This case cannot be handled by prior art systems. Thus, the system described here has the potential to be part of the U.S. Pat. 5,572,428 to Ishida, for example.

The network analogy can be extended if each vehicle receives and retransmits all received data as a single block of data. In this way, each vehicle is assured in getting all of the relevant information even if it gets it from many sources. Even with many vehicles, the amount of data being transmitted is small relative to the bandwidth of the infrared optical or radio technologies. Naturally, in some particular cases, a receiver and retransmitter can be part of the highway infrastructure. Such a case might be on a hairpin curve in the mountains where the oncoming traffic is not visible.

In some cases, it may be necessary for one vehicle to communicate with another to determine which evasive action each should take. This could occur in a multiple vehicle situation when one car has gone out of control due to a blowout, for example. In such cases, one vehicle may have to tell the other vehicle what evasive actions it is planning. The other vehicle can then calculate whether it can avoid a collision based of the planned evasive action of the first vehicle and if not it can inform the first vehicle that it must change its evasive plans. The other vehicle would also inform the first vehicle as to what evasive action it is planning. Several vehicles communicating in this manner can determine the best paths for all vehicles to take to minimize the danger to all vehicles.

If a vehicle is stuck in a corridor and wish to change lanes in heavy traffic, the operator's intention can be signaled by the operator activating the turn signal. This could send a message to other vehicles to slow down and let the signaling vehicle change lanes. This would be particularly helpful in an alternate merge situation.

4. Communication with highway - Maps

4.1 Statement of the Problem

The initial maps showing roadway lane and boundary location for the CONUS should preferably be installed within the vehicle at the time of manufacture. The vehicle thereafter would check on a section by section basis whether it had the latest update information for the particular and surrounding locations where it is being operated. One method of verifying this information would be achieved if a satellite periodically broadcasts the latest date and time that each segment had been most recently updated. This matrix would amount to a small transmission requiring perhaps one minute of airtime. Any additional emergency information could also be broadcast in between the periodic transmissions to cover accidents,

trees falling onto roads etc. If the periodic transmission were to occur every five minutes and if the motion of a vehicle were somewhat restricted until it had received a periodic transmission, the safety of the system can be assured. If the vehicle finds that it does not have the latest map information, the cell phone in the vehicle can be used to log onto the Internet, for example, and the missing data downloaded. An alternate is for the LEOs to broadcast the map corrections directly.

It is also possible that the map data could be off loaded from a transmitter on the highway itself. In that manner, the vehicles would only obtain that map information which it needed and the map information would always be up to the minute. As a minimum, temporary data communication stations can be placed before highway sections that are undergoing construction or where a recent blockage has occurred and where the maps have not yet been updated. Such an emergency data transfer would be signaled to all approaching vehicles to reduce speed and travel with care. Naturally such information could also contain maximum and minimum speed information which would limit the velocity of vehicles in the area.

There is other information that would be particularly useful to a vehicle operator or control system, including in particular the weather conditions especially at the road surface. Such information could be obtained by road sensors and then transmitted to all vehicles in the area by a permanently installed system. Alternately, there have been recent studies that show that icing conditions on road surfaces, for example, can be accurately predicted by local meteorological stations and broadcast to vehicles in the area. In such a system is not present, then, the best place to measure road friction is at the road surface and not on the vehicle. The vehicle requires advance information of an icing condition in order to have time to adjust its speed or take other evasive action. The same road based or local meteorological transmitter system could be used to warn the operators of traffic conditions, construction delays etc. and to set the local speed limit.

4.2 Maps

All information regarding the road, both temporary and permanent, should be part of the map data base, including speed limits, presence of guard rails, width of each lane, width of the highway, width of the shoulder exactly where the precise position location apparatus is located, etc. The Speed limit associated with particular locations on the maps should be coded in such a way that the speeds limit can depend upon the time of day and the weather conditions. In other words, the speed limit is a variable that will change from time to time depending on conditions. It is contemplated that there will be a display for various map information present which will always ba in view for the passenger and for the driver at least when the vehicle is operating under automatic control. Additional user information can thus also be displayed such as traffic conditions, weather conditions, advertisements, locations of restaurants and gas stations, etc.

A map showing the location of road and lane boundaries can be easily generated using a specially equipped survey vehicle that has the most accurate position measurement system available. In some cases, it might be necessary to set up one or more temporary local DGPS base stations in order to permit the survey vehicle to know its position within a few centimeters. The vehicle would drive down the roadway while operators, using specially designed equipment, sight the road edges and lanes. This would probably best be done with laser pointers and cameras. Transducers associated with the pointing apparatus record

the angle of the apparatus and then by triangulation determine the distance of the road edge or lane marking from the survey vehicle. Since the vehicle's position would be accurately known, the boundaries and lane markings can be accurately determined. It is anticipated that the mapping activity would take place continuously such that all roads in a particular state would be periodically remapped in order to pickup up any changes which were missed by other monitoring systems and to improve the reliability of the maps by minimizing the chance for human error.

The above described method depends on human skill and attention and thus is likely to result in many errors. A preferred approach is to carefully photograph the edge of the road and use the laser pointers to determine the location of the road lines relative to the pointers and to determine the slope of the roadway through triangulation. In this case several laser pointers would be used emanating from above, below and to the sides of the camera. The reduction of the data is then done later using equipment that can automatically pick out the lane markings and the reflected spots from the laser pointers.

In some cases where the roadway is straight, the survey vehicle could travel at moderate speed while obtaining the boundary and lane location information. In other cases, where the road in turning rapidly, more readings would be required per mile and the survey vehicle would need to travel more slowly. In any case, the required road information can be acquired semi-automatically with the survey vehicle traveling at a moderate speed. Thus, the mapping of a particular road would not require significant time or resources. It is contemplated that a few such survey vehicles could map all of the major roads in the United States in less than one year.

The mapping effort could be supplemented and cross-checked though the use of accurate detailed digital photogrammetic systems which, for example, can determine the road altitude with an accuracy to <50 cm. Efforts are underway to map the earth with 1 meter accuracy. The generated maps could be used to check the accuracy of the road determined maps.

Another improvement that can be added to the system based on the maps is to use a heads up display for in-vehicle signage. As the vehicle travels down the road, the contents of road side signs can be displayed on a heads up display, providing such a display is available in the vehicle, or on a specially installed LCD display. This is based on the inclusion in the map database the contents of all highway signs. A further improvement would be to include signs having varying messages which would require that the message be transmitted to the vehicle and received and processed for in vehicle display.

As the roadway is being mapped, the availability of GPS satellite view and the presence of multipath reflections from fixed structures can also be determined. This information can then be used to determine the advisability of locating a local precise location system at a particular spot on the roadway. Cars can also be used as probes for this process and for continuous improvement to check the validity of the maps and report any errors.

Multipath is the situation where more than one signal from a satellite comes to a receiver with one of the signals resulting from a reflection off of a building or the ground, for example. Since multipath is a function of geometry, the system can be designed to eliminate its effects based on highway surveying and appropriate antenna design. Multipath from other vehicles can also be eliminated since the location of the other vehicles will be known.

4.3 **Privacy**

People do not necessarily want the government to know where they are going and therefore will not want information to be transmitted that can identify the vehicle. The importance of this issue may be overestimated. Most people will not object to this minor infraction if they can get to their destination more efficiently and safely.

On the other hand, it has been estimated that there are 100,000 vehicles on the road, many of them stolen, where the operators do not want the vehicle to be identified. If an identification process that positively identifies the vehicle were made part of this system, it could thus cut down on vehicle theft. Alternately, thieves might attempt to disconnect the system thereby defeating the full implementation of the system and thus increasing the danger on the roadways and defeating the RtZF objective. The state of the system would therefore need to be self-diagnosed.

5. Sensing of non-RtZF equipped objects

5.1 **Problem Statement**

Vehicles with the RtZF™ system of this invention must also be able to detect those vehicles that do not have the system as well as pedestrians, animals, bicyclists, and other hazards that may cross the path of the equipped vehicle.

5.2 **Prior Art**

Although, there appears not to be any significant prior art involving a vehicle communicating safety information to another vehicle on the roadway, several of the prior art patents discuss methods of determining that a collision might take place using infrared and radar. U.S. Pat. 5,249,128 to Markandey et al., for example, discusses methods of using infrared to determine the distance to a vehicle in front and U.S. Pat. 5,506,584 to Boles discloses a radar based system. Both systems suffer from a high false alarm rate and could be substantially improved if a pattern recognition system such as neural networks were used.

5.3 **Description**

Systems based on radar have suffered from the problem of being able to sufficiently resolve the images which are returned to be able to identify the other vehicles, bridges, etc. One method used for adaptive cruise control systems is to ignore everything that is not moving. This, of course, leads to accidents if this were used with the instant invention. The problem stems from the resolution achievable with radar unless the antenna is made very large. Since this is impractical for use with automobiles, only minimal collision avoidance can be obtained using radar.

Optical systems can provide the proper resolution but may require illumination with a bright light or laser. If the laser is in the optical range, there is a danger of causing eye damage to pedestrians or vehicle operators. As a minimum it will be found distracting and annoying to other vehicle operators. A laser operating in the infrared part of the electromagnetic spectrum avoids the eye danger problem and, since it will not be seen, it will not be annoying. Infrared also has the proper resolution so that pattern recognition technologies can be employed to recognize various objects, such as vehicles, in the reflected image. Infrared has another advantage from the object recognition perspective. All objects radiate and reflect infrared. The hot engine of a moving vehicle in particular is a recognizable signal. Thus, if the area around a vehicle is observed with both passive and active infrared, more information can be obtained than

from radar, for example. Infrared is less attenuated by fog than optical frequencies, although it is not as good as radar. Infrared is also attenuated by snow but at the proper frequencies it has about five times the range of human sight.

An example of such an instrument is made by Sumitomo Electric and is sufficient for the purpose here. The Sumitomo product has been demonstrated to detect leaves of a tree at a distance of 300 meters. The product operates at a 1.5 micron wavelength.

This brings up a philosophical discussion about the trade-offs between radar with greater range and infrared laser radar with more limited range but greater resolution. At what point should driving during bad weather conditions be prohibited? If the goal of zero fatalities is to be realized, then people should not be permitted to operate their vehicles during dangerous weather conditions. This may require closing roads and highways prior to the start of such conditions. Under such a policy a system which accurately returns images of obstacles on the roadway that are five times the visual distance should be adequate. In such a case, radar would not be necessary. These and other similar design trade-off issues will be resolved prior to the submission of a proposal for a Phase One IVI effort.

Laser Radar scanning system

The digital map can be used to define the field that the laser radar scanner will interrogate. The laser radar scanner will return information as to distance to an object in the scanned field. This will cover all objects that are on or adjacent to the highway. The laser pulse can be a pixel that is one inch in diameter at 100 feet, for example. The scanner must scan the entire road at such a speed that the motion of the car can be considered significant. Alternately, a separate aiming system that operates at a much lower speed, but at the speed to permit compensation for the car angle changes. Such an aiming system is also necessary due to the fact that the road curves up and down. Therefore two scanning methods, one a slow, but for large angle motion and the other fast but for small angles are required. The large angular system requires a motor drive while the small angular system can be accomplished through the use of an acoustic wave system, such as Lithium Niobate ($LiNbO_3$), which is used to drive a crystal which has a large refractive index such as Tellurium dioxide.

The laser radar scanner can be set up in conjunction with a range gate so that once it finds a object the range can be narrowed so that only that object and other objects at the same range, 65 to 75 feet for example, are allowed to pass the receiver. In this way an image of a vehicle can be separated from the rest of the scene for identification by pattern recognition software. Once the image of the particular object has been captured , the range gate is broadened, to 20 to 500 feet for example, and the process repeated for another object. In this manner all objects in the field of interest to the vehicle can be separated and individually imaged and identified. The field of interest, of course, is the field where all objects with which the vehicle can potentially collide reside. Particular known features on the highway can be used as aids to the scanning system so that the pitch and perhaps roll angles of the vehicle can be taken into account.

Prior to the time that all vehicles are equipped with the RtZF™ system described above, roadways will consist of a mix of vehicles. In this period it will not be possible to totally eliminate accidents. It will be possible to minimize the probability of having an accident however, if a laser radar system similar to

that described in Shaw US Pat. 5,529,138 with some significant modifications is used. It is correctly perceived by Shaw that the dimensions of a radar beam are too large to permit distinguishing various objects which may be on the roadway in the path of the instant vehicle. Laser radar provides the necessary resolution that is not provided by radar. Laser radar as used in the present invention however would acquire significantly more data than anticipated by Shaw. Sufficient data in fact would be attained to permit the acquisition of a 3-dimensional image of all objects in the field of view. The X and Y dimensions of such objects would, of course, be determined knowing the angular orientation of the laser radar beam. The longitudinal or Z dimension would be obtained by the time-of-flight of the laser beam to a particular point on the object and reflected back to the detector.

At least two methods are available for resolving the longitudinal dimension for each of the pixels in the image. In one method, a laser radar pulse having a pulse width of say one nanosecond would be transmitted toward the area of interest and as soon as the reflection was received and the time-of-flight determined, a new pulse would be sent at a slightly different angular orientation. The laser, therefore, would be acting as a scanner covering the field of interest. A single detector could then be used since it would know the pixel that was being illuminated. The distance to the reflection point could be determined by time-of-flight thus giving the longitudinal distance to all points in view on the object.

Alternately, the entire area of interest can be illuminated and an image focused on a CCD or CMOS array. By checking the time-of-flight to each pixel, one at a time, the distance to that point on the vehicle would be determined. A variation of this would be to use a garnet crystal as a pixel shutter and only a single detector. In this case the garnet crystals would permit the illumination to pass through one pixel at a time through to a detector.

Other methods of associating a distance to a particular reflection point, of course, can now be conceived by those skilled in the art. In the laser scanning cases, the total power required of the laser if significantly less than in the area of illuminated design. However, the ability to correctly change the direction of the laser beam in a sufficiently short period of time complicates the scanning design. The system would work approximately as follows: The entire area in front of the instant vehicle, perhaps as much as a full 180 degree arc in the horizontal plane would be scanned for objects. Once one or more objects had been located, the scanning range would be severely limited to basically cover that particular object and some surrounding space. Based on the range to that object a range gate can be used to eliminate all background and perhaps interference from other objects. In this manner, a very clear picture or image of the object of interest can be obtained as well as its location and, through the use of a neural network pattern of recognition system, the identity of the object can be ascertained as to whether it is a sign, a truck, an automobile or other objects. The identification of the object will permit an estimate to be made of the object's mass and thus the severity of any potential collision.

Once a pending collision is identified, this information can be made available to the driver and if the driver ceases to heed the warning, control of the vehicle could be taken from him or her by the system. The actual usurpation of vehicle control, however, is unlikely since there are many situations on the highway where the potential for a collision cannot be accurately ascertained. Consequently, this system can be thought of as an interim solution until all vehicles have the RtZF™ system described above.

To use the laser radar in a scanning mode requires some means of changing the direction of the emitted pulses of light. One method of using a ultrasonic wave to change the difraction angle of a Tellurium dioxide crystal was disclosed above. This can also be done in a variety of other ways such as through the use of a spinning mirror. such as is common with laser scanners and printers. This mirror would control the horizontal scanning, for example. with the vertical scanning controlled though a stepping motor. Alternately, one or more piezoelectric materials can be used to cause the laser radar transmitter to rotate about a pivot point. A rotating system, such as described in Shaw is the least desirable available methods due to the difficulty in obtaining a good electrical connection between the laser and the vehicle while the laser is spinning at a very high angular velocity. Another promising technology is to use MEMS mirrors to deflect the laser beam.

Although the system described above is intended for collision avoidance or at least the notification of a potential collision, when the roadway is populated by vehicles having the RtZF™ system and vehicles which do not, its use is still desirable after all vehicles are properly equipped. It can be used to search for animals or other objects which may be on or crossing the highway, a box dropping off of a truck for example, a person crossing the road who is not paying attention to traffic, naturally motorcycles, bicycles, and other vehicles can also be monitored.

One significant problem with all previous collision avoidance systems which use radar or laser radar systems to predict impacts with vehicles, is the inability to know whether the vehicle that is being interrogated is located on the highway or is off the road. In the system of the present invention, the location of the road at any distance ahead of the vehicle would be known precisely from the sub-meter accuracy maps, thus the scanning system can ignore, for example, all vehicles on lanes where there is a physical barrier separating the lanes from the lane on which the subject vehicle is traveling. This, of course, is a common situation on super highways. Similarly, a parked car on the side of the car would not be confused with a parked car that is in the lane of travel of the subject vehicle when the road is curving. This permits the subject invention to be used for automatic cruise control. In contrast with radar systems, it does not require that vehicles in the path of the subject vehicle to be moving, thus high speed impacts into stalled traffic can be avoided.

If we use a system with a broader beam to illuminate a larger area on the road in front of the subject vehicle, and the subsequent focusing of this image onto a CCD or CMOS array, this has an advantage of permitting a comparison to be made of the passive infrared signal and the reflection of the laser radar active infrared. Metal objects, for example appear cold to passive infrared. This permits another parameter to be used to differentiate metallic objects from non-metallic objects such as foliage or animals such as deer. The breadth of the beam can be controlled and thereby a particular object can be accurately illuminated. With this system, the speed with which the beam steering is accomplished can be much slower. Naturally, both systems can be combined into the maximum amount of information to be available to the system.

Through the use of range gating, objects can be relatively isolated from the environment surrounding it other than for the section of highway. For many cases, a properly trained neural network can use this data and identify the objects. An alternate approach is to use the Fourier transform of the scene as

input to neural network. The advantages of this latter approach are that the particular location of the vehicle in the image is not critical for identification.

In the future. when the system can take control of the vehicle. it will be possible to have much higher speed travel. In such cases all vehicles on the controlled roadway will need to have the RtZF™ system as described above. Fourier transforms of the objects of interest can be done optically though the use of a diffraction system. The Fourier transform of the scene can then be compared with the library of the Fourier transforms of all potential objects and through a system used in military target recognition, multiple objects can be recognized and the system then focus onto one at time to determine the degree of threat that it poses.

6. ITS + Adaptive Cruise Control

6.1 Problem - Traffic Congestion

The world is experiencing an unacceptable growth in traffic congestion and attention is increasingly turning to smart highway systems to solve the problem. It has been estimated that approximately $240 billion will be spent on smart highways over the next 20 years. All of the initiatives currently being considered involve a combination of vehicle mounted sensors and sensors and other apparatus installed in or on the roadway. Such systems are expensive to install. difficult and expensive to maintain and will thus only be used on major highways if at all. Although there will be some safety benefit from such systems, it will be limited to the highways which have the system and perhaps to only a limited number of lanes.

The RtZF™ of this invention eliminates the shortcomings of the prior art by providing a system that does not require modifications to the highway. The information as to the location of the highway is determined. as discussed above, by mapping the edges of the roadway using a process whereby the major roads of the entire country can be mapped at very low cost. Thus. the system has the capability of reducing congestion as well as saving lives on all major roads, not just those which have been chosen for high speed guided lanes.

6.2 Description

According to U.S. Pat. 5.506.584 the stated goals of the US DOT IVHS system is:

- improving the safety of surface transportation
- increasing the capacity and operational efficiency of the surface transportation system
- enhancing personal mobility and the convenience and comfort of the surface transportation system
- reducing the environmental and energy impacts of the surface transportation system

The RtZF™ of the present invention satisfies all of these goals at a small fraction of the cost of prior art systems. The safety benefits have been discussed above. The capacity increase is achieved by confining vehicles to corridors where they are then permitted to travel at higher speeds. This can be achieved immediately where carrier phase DGPS is available or with the implementation of the highway located precise location systems as shown in FIG. 6. An improvement is to add the capability for the speed of the vehicles to be set by the highway. This is a simple additional few bytes of information that can be transmitted along with the road edge location map, thus. at very little initial cost. To account for the tolerances in vehicle speed control systems. the scanning laser radar. or other technology system. which

monitors for the presence of vehicles without RtZF™ is also usable as an adaptive cruise control system. Thus, if a faster moving vehicle approaches a slower moving vehicle, it will automatically slow down to keep a safe separation distance from the leading vehicle. Thus, although the system is not planned for platooning, that will be the automatic result in some cases. Thus, the maximum packing of vehicles is automatically obtained and thus the maximum vehicle flow rate is also achieved with a very simple system.

For the Intelligent Highway System (ITS) application, provision is required to prevent unequipped vehicles from entering the restricted lanes. In most cases, a barrier will be required since if an errant vehicle did enter the controlled lane, a serious accident could result. Vehicles would be checked while traveling down the road or at a tollbooth, or similar station, that the RtZF™ system was in operation without faults and with the latest updated map for the region. Only those vehicles with the RtZF™ system in good working order would be permitted to enter. The speed on the restricted lanes would be set according to the weather conditions and fed to the vehicle information system automatically as discussed above.

For ITS use, there needs to be a provision whereby a driver can signal an emergency, for example, by putting on the hazard lights. This would permit the vehicle to leave the roadway and enter the shoulder when the vehicle velocity is below some level. Once the driver provides such a signal, the roadway information system, or the network of vehicle based control systems, would then reduce the speed of all vehicles in the vicinity until the emergency has passed. This roadway information system need not be actually associated with the particular roadway and also need not require any roadway infrastructure. It is a term used here to represent the collective system as operated by the network of nearby vehicle and the inter-vehicle communication system. Eventually, the occurrence of such emergency situations will be eliminated by vehicle based failure prediction systems.

6.3 Enhancements - Vehicle

There will be emergency situations develop on intelligent highways. It is difficult to access the frequency or the results. The industry has learned from airbags that if a system is developed which saves many lives but causes a few deaths, the deaths will not be tolerated. The ITS system, therefore, must operate with a very high reliability, that is approaching zero fatalities. Since the brains of the system will reside in each vehicle, which is under the control of individual owners, there will be malfunctions and the system must be able to adapt without causing accidents.

The spacing of the vehicles is the first line of defense. Secondly, each vehicle with a RtZF™ has the ability to automatically communicate to all adjacent vehicles and thus immediately issue a warning when an emergency event is occurring. Finally, with the addition of a total vehicle diagnostic system, such as disclosed in U.S. Pat. No. 5,809,437, " On Board Vehicle Diagnostic System", potential emergencies can be anticipated and thus eliminated with high reliability.

Although the application for ITS envisions a special highway lane and high speed travel, the potential exists in the present invention to provide a lower measure of automatic guidance where the operator can turn control of the vehicle over to the RtZF™ for as long as the infrastructure is available. In this case, the vehicle would operate on normal lanes but would retain its position in the lane and avoid collisions until a decision requiring operator assistance is required. At that time the operator would be

notified and if he or she did not assume control of the vehicle, an orderly stopping of the vehicle on the side of the road would occur.

For all cases where vehicle steering control is assumed by the RtZF™, the algorithm for controlling the steering should be developed using neural networks or neural fuzzy systems. This is especially true for the emergency cases discussed above where it is well known that operators frequently take the wrong actions and at the least they are slow to react. Algorithms developed by other non-pattern recognition techniques do not in general have the requisite generality or complexity and are also likely to make the wrong decisions. When the throttle and breaking functions are also handled by the system, an algorithm based on neural networks is even more important.

For the ITS, the driver will enter his designation so that the vehicle knows ahead of time where to exit. Alternately, if the driver wishes to exit he merely turns on his turn signal, which tells the system and other vehicles that he or she is about to exit the controlled lane.

7. Other Features

7.1 Blind spot Detection

The RtZF™ system of this invention also can eliminate the need for blind spot detectors such as disclosed in U.S. Pat. 5,530,447 to Henderson. Alternately, if a subset of the complete RtZF™ is implemented, as is expected in the initial period, the RtZF™ can be made compatible with the blind spot detector described in the '447 patent.

7.2 Incapacitated Driver

As discussed above, the RtZF™ system of this invention also handles the problem of the incapacitated driver thus eliminating the need for sleep sensors that appear in numerous U.S. Patents. Such systems have not been implemented because of their poor reliability. The RtZF™ system senses the result of the actions of the operator, which could occur for a variety of reasons including old age, drunkenness, heart attacks, drugs as well as falling asleep.

7.3 Emergencies - car jacking, crime

Another enhancement that is also available is to prevent car jacking in which case the RtZF™ can have the functions of a Lojack system. In the case where a car jacking occurs, the location of the vehicle can be monitored and if an emergency button is pushed, the location of the vehicle with the vehicle ID can be transmitted.

7.4 Headlight Dimmer

The system also solves the automatic headlight dimmer problem. Since the RtZF™ equipped vehicle knows where all other RtZF™ equipped vehicles are located in its vicinity, it knows when to dim the headlights. Since it is also interrogating the environment in front of the vehicle it also knows the existence and approximate location of all non RtZF™ equipped vehicles. This is one example of a future improvement to the system. The RtZF™ is a system which lends itself to continuous improvement without having to change systems on an existing vehicle.

7.5 Rollover

It should be obvious from the above discussion that rollover accidents should be effectively eliminated by the RtZF™. In the rare case where one does occur, the RtZF™ has the capability to sense that event since the location and orientation of the vehicle is known.

For large trucks that have varying inertial properties depending on the load that is being hauled, sensors can be placed on the vehicle that measure the angular and linear acceleration of a part of the vehicle. Since the geometry of the road is known, the inertial properties of the vehicle with load can be determined and thus the tendency of the vehicle to roll over can be determined. Again since the road geometry is known the speed of the truck can then be limited to prevent rollovers.

8. Anticipatory sensing - Smart Airbags, Evolution of the System

The RtZF™ is also capable of enhancing other vehicle safety systems. In particular, through knowing the location and velocity of other vehicles, for those cases where an accident cannot be avoided, the RtZF™ will in general be able to anticipate a crash and make an assessment of the crash severity using neural network technology. Even with a limited implementation of RtZF™ a significant improvement in smart airbag technology results when used in conjunction with a collision avoidance system such as described in Shaw U.S. Patents 5,314,037 and 5,529,138 and a neural network anticipatory sensing algorithm such as disclosed in co-pending U.S. Patent application 08/247,760 to Breed. A further enhancement would be to code the signal from RtZF™ vehicles with information that includes the size and approximate weight of the vehicle. Then if an accident is inevitable, the severity can be accurately anticipated and the smart airbag tailored to the pending event.

It can be seen by the above discussion that the RtZF™ will evolve in solving many safety, vehicle control and ITS problems. Even such technologies as steering and drive by wire will be enhanced by the RtZF™ of this invention since it will automatically adjust for failures in these systems and prevent accidents.

9. Other advantages & Enhancements

9.1 GPS and Other Measurement Improvements

One of the problems with the RtZF™ is operation in large cities such as downtown New York. In such locations, unless there are a plurality of local pseudolites or precise position location system installations, the signals from the GPS satellites can be significantly blocked. Also there is a severe multipath problem. A solution is to use the LORAN system as a backup for such locations. The accuracy of LORAN can be comparable to DGPS. Naturally, the use of multiple roadway located triple precise positioning systems would be a better solution or a complementary solution.

The use of geo-synchronous satellites as a substitute for earth bound base stations in a DGPS system, with carrier phase enhancements for sub-meter accuracies, is also a likely improvement to the RtZF™ system that can have a significant effect in downtown areas.

Another enhancement that would be possible with dedicated satellites and/or earth bound pseudolites results from the greater control over the information transmitted than is available from the GPS system. Recognizing that this system could save up to 40,000 lives per year in the U.S. alone, the cost of deploying such special purpose stations can easily be justified. For example, say there exists a modulated wave that is 10000 kilometers long, another one which is 1000 km long etc. down to 1 cm. It would then

be easy to determine the absolute distance from one point to the other. Other types of modulation are of course possible to achieve the desired result of simply eliminating the carrier integer uncertainty that is discussed in many U.S. patents and other literature. This is not meant to be a recommendation but to illustrate that once the decision has been made to provide information to every vehicle that will permit it to always know its location within 10 cm, many technologies will be there to make it happen. The cost savings resulting from eliminating fatalities and serious injuries will easily pay the cost of such technologies many times over.

9.2 Vehicle Enhancements

The RtZF™ system can now be used to improve the accuracy of other vehicle based instruments. The accuracy of the odometer and yaw rate sensors can be improved over time, for example, by regression against the DGPS data.

9.3 Highway Enhancements

Enhancements to the roadways that result from the RtZF™ include traffic control. The timing of the stoplights can now be automatically adjusted based on the relative traffic flow. The position of every vehicle within the vicinity of the light will be known. When all vehicles have the RtZF system, many stoplights will no longer be necessary since the flow of traffic through an intersection can be accurately controlled to avoid collisions.

Since the road conditions will now be known to the system, an enhanced RtZF™ system will be able to advise an operator not to travel or, alternately, it can pick an alternate route if certain roads have accidents or iced over roadways, for example. Some people may decide not drive if there is bad weather or congestion. The important point here is that sensors will be available to sense the road condition as to both traffic and weather, this information will be available automatically and not require reporting from a weather station which has only late and inaccurate information.

The system lends itself to time and congestion based allocation of highway facilities. A variable toll can automatically be charged to vehicles based on such considerations since the vehicle can be identified. In fact, automatic toll systems now being implemented will become obsolete as will all toll booths.

Finally, it is important to recognize that the RtZF system is not a "sensor fusion" system. Sensor fusion is based on the theory that you can take inputs from different sensors and combine them in such a way as to achieve more information from the combined sensors than from treating the sensor outputs independently in a deterministic manner. The ultimate sensor fusion system is based on artificial neural networks, sometimes combined with fuzzy logic to form a neural fuzzy system. Such systems are probabilistic. Thus there will always be some percentage of cases where the decision reached by the network will be wrong. The use of such sensor fusion, therefore, is inappropriate for the Zero Fatalities goal.

9.4 Map Enhancements

Once the road edge and lane locations are being transmitted to the operator, it requires very little additional bandwidth to include other information such as the location of all businesses that a traveler would be interested in such as gas stations, restaurants etc. which could be done on a subscription basis.

This concept was partially disclosed in the '482 patent discussed and partially implemented in existing map databases.

Naturally, the communication of information to the operator could be done either visually or orally as described in U.S. Pat. 5.177.685. Finally, the addition of a route guidance system as disclosed in other patents becomes even more feasible since the exact location of a destination can be determined. The system can be configured so that an operator could enter a phone number, for example, or an address and the vehicle would be automatically and safely driven to that location. Since the system knows the location of the edge of every roadway, very little if nay operator intervention would be required. Even a cell phone number can be used if the cell phone has the SnapTrack GPS location system as soon to be provided vy Qualcom.

9.5 Other Uses

The RtZF™ can even replace other sensors now on or being considered for automobile vehicles including Pitch, roll and yaw sensors. This information can be found by using carrier phase GPS and by adding more antennas to the vehicle. Additionally, once the system is in place for land vehicles, there will be many other applications such as surveying, vehicle tracking and aircraft landing which will benefit from the technology and infrastructure improvements. The automobile safety issue and ITS will result in the implementation of a national system which provides any user with low cost equipment the ability to know precisely where he is within centimeters on the face of the earth. Many other applications will undoubtedly follow.

10. The RtZF™ System

The design of this system is only beginning. From the above discussion two conclusions should be evident. There are significant advantages in accurately knowing where the vehicle, the roadway and other vehicles are and that this information is the key to reducing fatalities to zero. Secondly, there are many technologies that are already in existence that can provide this information to each vehicle. Once there is a clear direction that this is the solution then many new technologies will emerge. There is nothing inherently expensive about these technologies and once the product life cycle is underway the added cost to vehicle purchasers will be minimal. Roadway infrastructure costs will be minimal and system maintenance costs almost non-existent.

Most importantly, the system has the capability of reducing fatalities to zero!

10.1 Technical Issues

The accuracy of DGPS has been demonstrated numerous times in small controlled experiments, most recently by the University of Minnesota.

The second technical problem is the integrity of the signals being received and the major cause of the lack of integrity is the multi-path effect. Considerable research has gone into solving the multi-path effect and Trimble claims that this problem is no longer an issue.

The third area is availability of GPS and DGPS signals to the vehicle as it is driving down the road. The system is designed to tolerate temporary losses of signal, up to a few minutes. That is the prime function of the inertial guidance system (INS). Prolonged absence of the GPS signal will significantly degrade system performance. There are two primary causes of lack of availability, temporary and

permanent. Temporary causes result from a car driving between two trucks for an extended period of time, blocking the GPS signals. The eventual solution to this problem is to change the laws to prevent trucks from traveling on both sides of the automobile. If this remains a problem a warning will be provided to the driver that he/she is losing system integrity and therefore he/she should speed up or slow down to regain a satellite view.

Permanent blockage of the GPS signals. as can come from operating the vehicle in a tunnel or in the downtown of a large city. can be corrected through the use of pseudolites or other guidance systems such as the SnapTrack system. This is not a serious problem since very few cars run off the road in a tunnel or in downtown Manhattan.

The final technical impediment is the operation of the diagnostic system that verifies that the system is operating properly. This requires an extensive failure mode and effect analysis and the design of a diagnostic system that answers all of the concerns of the FMEA.

10.2 Cost Issues

The primary cost impediment is the cost of the DGPS hardware. A single base station and roving receiver that will give an accuracy of 2 centimeters (1 σ) currently costs about $25.000. This is a temporary situation brought about by low sales volume. Since there is nothing exotic in the receiving unit, the cost can be expected to follow typical automotive electronic life-cycle costs and therefore we project that in high volume production the electronics for the DGPS receivers will be below $100 per vehicle. In the initial implementation of the system. an OmniSTAR DGPS system will be used providing an accuracy of 6 cm.

A similar argument can be made for the inertial navigation system. A considerable research and development effort is ongoing to reduce the size. complexity and cost of these systems. Three technologies are vying for this rapidly growing market: laser gyroscopes. fiber-optic lasers. and MEMS systems. The cost of these units today range from a few hundred and ten thousand dollars each. however. once again this is due to the very small quantity being sold. Substantial improvements are being made in the accuracies of the MEMS systems and it now appears that such a system will be accurate enough for RtZF purposes. We expect the cost of these systems in high-volume production will be below ten dollars each. This includes at least a yaw rate sensor with three accelerometers and probably three angular rate sensors. The accuracy of these units is currently approximately .003 degrees per second. This is a random error which can be corrected somewhat by the use of multiple vibrating elements. A new laser gyroscope has recently been announced by Intellisense Corporation which should provide a dramatic cost reduction and accuracy improvement.

Eventually when most vehicles on the road have the RtZF system then communication between the vehicles can be used to substantially improve the location accuracy of each vehicle as described above.

The cost of mapping the continental United States (CONUS) is largely an unknown at this time. OnmiStar has stated that they will map any area with sufficient detail at a cost of $300 per mile. They have also indicated the cost will drop substantially as the number of miles to be mapped increases. This mapping would be done by helicopter using their laser ranging system. We propose that the initial mapping be done using this system. However. a task of the Phase Zero project will be to investigate

alternate and potentially substantially less expensive mapping strategies. One such strategy, for example, would be to outfit a ground vehicle with the equipment that will determine the location of the lane and shoulder boundaries of road. Such a system has been used for mapping a Swedish highway. One estimate is that the mapping of a road will be reduced to approximately \$50 per mile for major highways and rural roads and a somewhat higher number for urban areas. The goal of this program is to map as much of the country as possible to an accuracy of 2 centimeters (1 σ).

Related to the costs of mapping is the cost of converting the raw data acquired either by helicopter or by ground vehicle into a usable map database. The cost for manually performing this vectorization process has been estimated at \$100 per mile by OmniSTAR. This process can be substantially simplified through the use of raster to vector conversion software. Such software is currently being used for converting hand drawings into CAD systems, for example. The Intergraph Corp. provides hardware and software for simplifying this task. It is therefore expected that the cost for vectorization of the map data will follow proportionately a similar path to the cost of acquiring the data and will eventually reach \$10 to \$20 per mile for the rural mapping and \$25 to a \$50 per mile for urban areas. Considering that there are approximately four million miles of roads in the CONUS, and assuming we can achieve an average of \$150 for acquiring the data and converting the data to a GIS database, the total cost for mapping all of the roads in United States will amount to \$600 million. This cost would obviously be spread over a number of years and thus the cost per year is manageable and small in comparison to the \$215 billion lost every year due to death, injury and lost time from congestion.

Another cost is the lack of DGPS base stations. The initial analysis indicated that this would be a serious problem as using the latest DGPS technology required a station every 30 miles. Upon further research, however, it has been determined that the OmniSTAR company has now deployed a nationwide DGPS system with 6 cm accuracy. The initial goal of the RtZF system was to achieve 2 cm accuracy for both mapping and vehicle location. The 2 cm accuracy can be obtained in the map database since temporary differential base stations will be installed for the mapping purposes. By relaxing the 2 cm requirement to 6 cm, the need for base stations every 30 miles disappears and the cost of adding a substantial number of base stations is no longer a factor.

The next impediment is the lack of a system for determining when changes are planned for the mapped roads. This will require communication with all highway and road maintenance organizations in the mapped area.

A similar impediment to the widespread implementation of this RtZF system is the lack of a communication system for supplying map changes to the equipped vehicles.

10.3 Educational issues

A serious impediment to the implementation of this system that is related to the general lack of familiarity with the system, is the belief that significant fatalities and injuries on the U.S. highways are a fact of life. This argument is presented in many forms such as "the perfect is the enemy of the good". This leads to the conclusion that any system which portends to reduce injury should be implemented rather than taking the viewpoint that driving an automobile is a process and as such it can be designed to achieve perfection. As soon as it is admitted that perfection cannot be achieved, then any fatality gets immediately

associated with this fact. This of course was the prevailing view among all manufacturing executives until the zero defects paradigm shift took place. The goal of Zero Fatalities is not going to be achieved in a short period of time. Nevertheless to plan anything short of zero fatalities is to admit defeat and to thereby allow technologies to enter the market that are inconsistent with a zero fatalities goal.

10.4 Potential Benefits When the System is Deployed.

10.4.1 Assumptions for the Application Benefits Analysis

- The high volume incremental cost of an automobile will be $200
- The cost of DGPS correction signals will be a onetime charge of $50 per vehicle.
- The benefits to the vehicle owner from up-to-date maps and to the purveyors of services located on these maps to cover the cost of updating the maps from as the roads change.
- The cost of mapping substantially all roads in the Continental U.S. will be $600 million.
- The effects of phasing in the system will be ignored.
- There are 15 million vehicles sold in the U.S. each year.
- Of the 40.000 plus people killed on the roadways. at least 10 % are due to road departure. yellow line infraction. stop sign infraction, excessive speed and other causes which will be eliminated by the Phase Zero deployment.
- $165 billion are lost each year due to highway accidents.
- The cost savings due to secondary benefits will be ignored.

10.4 Initial System Deployment

The initial implementation of the RtZF system would include the following services:

1. A warning is issued to the driver when the driver is about to depart from the road.
2. A warning is issued to the driver when the driver is about to cross a yellow line.
3. A warning is provided to the driver when the driver is exceeding a safe speed limit for the road geometry.
4. A warning is provided to the driver when the driver is about to go through a stop sign without stopping.
5. A warning is provided to the driver when the driver is about run the risk of a rollover.
6. A warning will be issued prior to a rear end impact by the equipped vehicle.
7. In-vehicle signage will be provided for highway signs.
8. A recording will be logged whenever a warning is issued.

11. Detailed Description of the Illustrations

Fig. 1 shows the current GPS satellite system associated with the earth and including 24 satellites 102, each satellite revolving in a specific orbital path 104 around the earth. By means of such a GPS satellite system. the position of any object can be determined with varying degrees of preciseness.

Fig. 2 shows an arrangement 202 of four satellites SV1,SV2,SV3 and SV4 of the GPS satellite system shown in Fig. 1 and a pseudolite 230 transmitting position information to receiver means of a base station 220, such as an antenna 222, which in turn transmits a differential correction signal via transmitter means associated with that base station, such as a second antenna 216, to a vehicle 218.

Fig. 3 is a logic diagram of the system 210 in accordance with the invention (illustrated in greater detail in Fig. 7) showing the combination of the GPS system 300 and an inertial navigation system 306. The GPS system includes a unit 302 for processing the received information from the satellites 301 of the GPS satellite system and data from an inertial reference unit (IRU) 304.

Additional details relating to Figs. 1-3 can be found in U.S. Pat. No. 5.606.506 to Kyrtsos.

Fig. 4 shows the implementation of the invention in which a vehicle 10 is traveling on a roadway in a defined corridor in the direction X. Each corridor is defined by lines 14. If the vehicle is traveling in one corridor and strays in the direction Y so that it moves along the line 22, e.g., the driver is falling asleep, the system on board the vehicle in accordance with the invention will be continually detecting the position of the vehicle, such as by means of the GPS system, and have stored the locations of the lines 14 defining the corridor. Upon an intersection of the position of the vehicle and one of the lines 14 as determined by a processor, the system may be designed to sound an alarm to alert the driver to the deviation or possibly even correct the steering of the vehicle to return the vehicle to within the corridor defined by a pair of lines 14.

Fig. 5 shows the implementation of the invention in which a pair of vehicles 26,30 are traveling on a roadway each in a defined corridor delineated by lines 14 and each is equipped with a system in accordance with the invention. The system will receive data informing it of the position of the other vehicle and prevent accidents from occurring.

Fig. 6 shows the implementation of the invention in which a pair of vehicles 26,30 are traveling on a roadway each in a defined corridor delineated by lines 14 and each is equipped with a system in accordance with the invention. The system will receive data informing it of the position of the other vehicle as well as the position of trees 51,52,53 on the side of the roadway and prevent accidents between the vehicles and between the vehicle and the trees 51,52,53 from occurring.

Fig. 7 is a schematic representation of the system 210 in accordance with the invention. System 210 detects the absolute position of the vehicle, such as by means of the GPS system 44 and has stored the locations of the edges of the roadways (the lines 14 defining the corridor as shown in Figs. 4-6) in a memory unit 46. Upon intersection of the position of the vehicle and the edges of the roadway as determined by a processor 48, the system may be designed to sound an alarm to alert the driver to the deviation or possibly even correct the steering of the vehicle to return the vehicle to within the corridor defined by a pair of lines 14 (the alarm and steering guidance unit being represented as reactive system 50). The position determining means 44 may include an optional inertial navigation system 54.

Means for determining the presence, location and/or velocity of other vehicles 56 on the roadway (any known type of detection system such as those using radar, electromagnetic radiation, etc.) are coupled to the processor 48 which can then determine the location of the other vehicles relative to the edges of the roadway and provide a signal to alert means 52 (e.g., an alarm) to alert the other vehicles if the location of the other vehicles approach close to an edge of the roadway or intersect with an edge of the roadway

A communications unit 58 is also coupled to the processor 48 to enable communication of data regarding, e.g., the location and velocity of the vehicle, between vehicles equipped with the same or a compatible system.

An automatic driving system 60 can be integrated with the steering unit and acceleration unit of the vehicle and coupled to the processor 48 to guide the vehicle in the roadway, i.e., such that the position of the vehicle does not come close to or intersect the edges of the roadway.

Fig. 8 is a flow chart of the method in accordance with the invention. The absolute position of the vehicle is determined at 62, e.g., using a GPS system, and compared to the edges of the roadway at 66 which is obtained from a memory unit 64. Based on the comparison at 66, it is determined whether the absolute position of the vehicle is approaching close to or intersects an edge of the roadway at 68. If not, then the position of the vehicle is again obtained and the process continues. If yes, an alarm will sound, a warning light will be illuminated or the system will take control of the vehicle (at 70) to guide it to a shoulder of the roadway or other safe location.

Claims:

We Claim:

1. A system for preventing vehicle accidents, comprising

position determining means for determining the absolute position of the vehicle.

memory means for storing data relating to edges of roadways on which the vehicle may travel,

processing means coupled to said determining means and said memory means for determining the location of the vehicle relative to the edges of the roadway, and

reaction means coupled to said processing means for affecting a system within the vehicle if the location of the vehicle approaches close to an edge of the roadway or intersects with an edge of the roadway.

2. The system of claim 1. wherein said position determining means comprise a unit which cooperates with a satellite system.

3. The system of claim 1. further comprising means for determining at least one of the presence, location and velocity of other vehicles on the roadway.

4. The system of claim 3. wherein said processing means are structured and arranged to determine the location of the other vehicles relative to the edges of the roadway.

5. The system of claim 1, further comprising communication means for enabling the vehicle to communicate with other vehicles similarly equipped with the accident preventing system such that the location and optionally velocity of the other vehicles is communicated to the vehicle.

6. The system of claim 1. further comprising automatic driving means coupled to said memory means and a steering unit and acceleration unit of the vehicle for guiding the vehicle within the edges of the roadway.

7. The system of claim 1, wherein said processing means are structured and arranged to receive data on at least one of weather conditions and traffic accidents and control operation of the vehicle based thereon.

8. The system of claim 1, wherein said position determining means comprise at least one earth-based station.

9. A method for preventing vehicle accidents. comprising the steps of

determining the absolute position of the vehicle.

storing data relating to edges of roadways on which the vehicle may travel,

determining the location of the vehicle relative to the edges of the roadway, and

affecting a system within the vehicle if the location of the vehicle approaches close to an edge of the roadway or intersects with an edge of the roadway.

10. The method of claim 9, further comprising the step of:
determining at least one of the presence, location and velocity of other vehicles on the roadway.

11. The method of claim 10, further comprising the step of:
determining the location of the other vehicles relative to the edges of the roadway.

12. The method of claim 9, further comprising the step of:
enabling the vehicle to communicate with other vehicles similarly equipped with the accident preventing system such that the location and optionally velocity of the other vehicles is communicated to the vehicle.

13. The method of claim 12, wherein the vehicles communicate with each other by utilizing a portion of the electromagnetic spectrum that permits only line of sight communication.

14. The system of claim 2, wherein the satellite system includes base stations for generating a differential correction signal to the vehicle.

15. The system of claim 1 wherein said position determining means further comprises an inertial navigation system.

16. The system of claim 4, further comprising alert means for alerting the other vehicles if the location of the vehicle approaches close to an edge of the roadway or intersect with an edge of the roadway.

17. The system of claim 1, wherein said processing means are structured and arranged to receive data on at least one of weather conditions and traffic accidents and display such data to the driver.

18. The system of claim 1, wherein said processor is structured and arranged to receive data on at least one of weather conditions and traffic accidents and control operation of the vehicle based thereon.

19. The system of claim 1, wherein said reaction means comprise an alarm.

20. The system of claim 1, wherein said reaction means comprise vehicle guidance system for automatically guiding the vehicle.

21. The method of claim 10, further comprising the step of:

alerting the other vehicles if the location of the vehicle approaches close to an edge of the roadway or intersects with an edge of the roadway.

22. A system for preventing vehicle accidents, comprising

a positioning system arranged in a vehicle for determining the absolute position of the vehicle,

a memory unit for storing data relating to edges of at least one lane of the roadway on which the vehicle may travel,

a processor coupled to said positioning system and said memory unit for determining the location of the vehicle relative to the edges of at least one lane of the roadway based on the absolute position of the vehicle and the data relating to edges of the roadway, and

a reactive component or system arranged in the vehicle and coupled to said processor, said component or system being arranged to initiate an action or change its operation if the location of the vehicle approaches close to an edge of at least one lane of the roadway or intersects with an edge of at least one lane of the roadway.

23. The system of claim 22, wherein said positioning system comprises a unit which cooperates with a satellite system.

24. The system of claim 23, wherein the satellite system includes base stations for generating a differential correction signal to the vehicle.

25. The system of claim 22, wherein said positioning system further comprises an inertial navigation system.

26. The system of claim 22, further comprising a determination system arranged on the vehicle for determining at least one of the presence, position and velocity of other vehicles on the roadway.

27. The system of claim 26, wherein said determination system determines the position of the other vehicles on the roadway relative to the vehicle, said processor being structured and arranged to determine the position of the other vehicles relative to the edges of at least one lane of the roadway based on the data relating to edges of at least one lane of the roadway.

28. The system of claim 27, further comprising a warning system for alerting the other vehicles if the location of the other vehicles approach close to an edge of the roadway or intersect with an edge of the roadway.

29. The system of claim 22, further comprising a communication unit for enabling the vehicle to communicate with other vehicles similarly equipped with the accident preventing system such that the location and optionally velocity of the other vehicles is communicated to the vehicle.

30. The system of claim 22, further comprising an automatic driving and guidance unit arranged in the vehicle and coupled to the memory unit and a steering unit and acceleration unit of the vehicle for guiding the vehicle within the edges of at least one lane of the roadway.

31. The system of claim 22, wherein said processor is structured and arranged to receive data on at least one of weather conditions and traffic accidents and control operation of the vehicle based thereon.

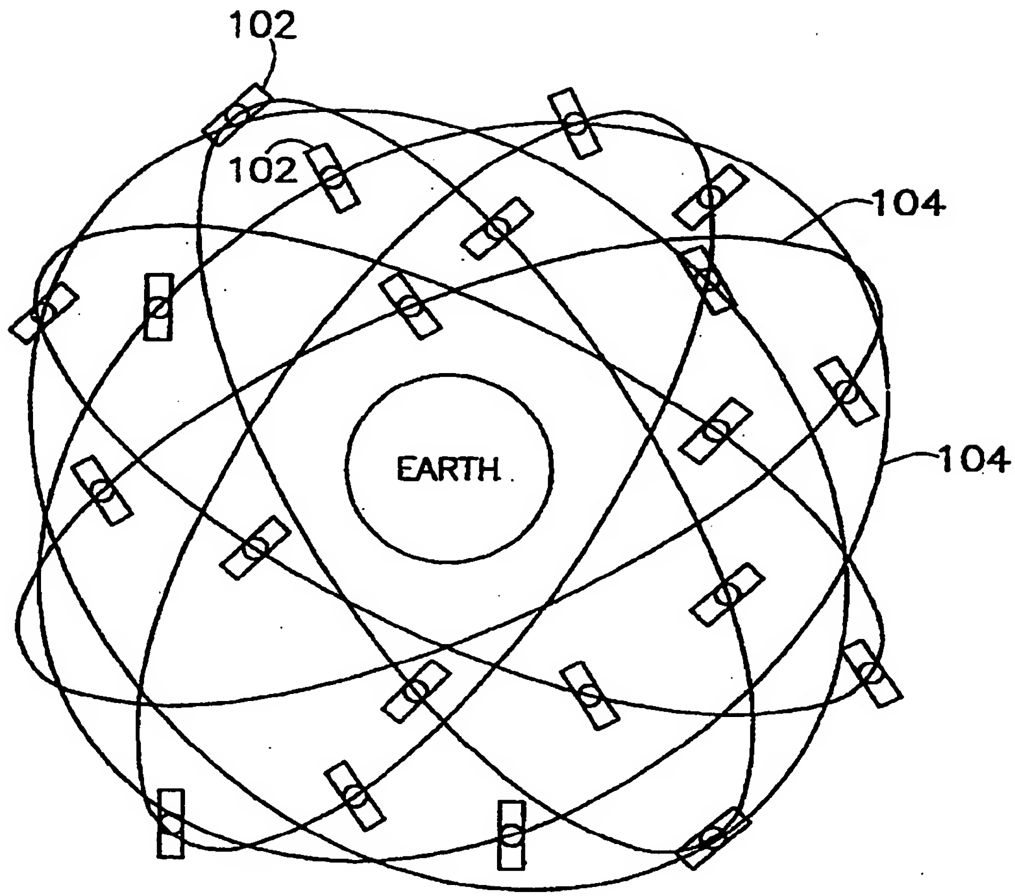
32. The system of claim 22, wherein said processor is structured and arranged to receive data on at least one of weather conditions and traffic accidents and display such data to the driver.

33. The system of claim 22, wherein said positioning system comprises at least one earth-based station.

34. The system of claim 22, wherein said reactive component or system is an alarm.

35. The system of claim 22, wherein said reactive component is a vehicle guidance system for automatically guiding the vehicle.

1/7



PRIOR ART

Fig. 1

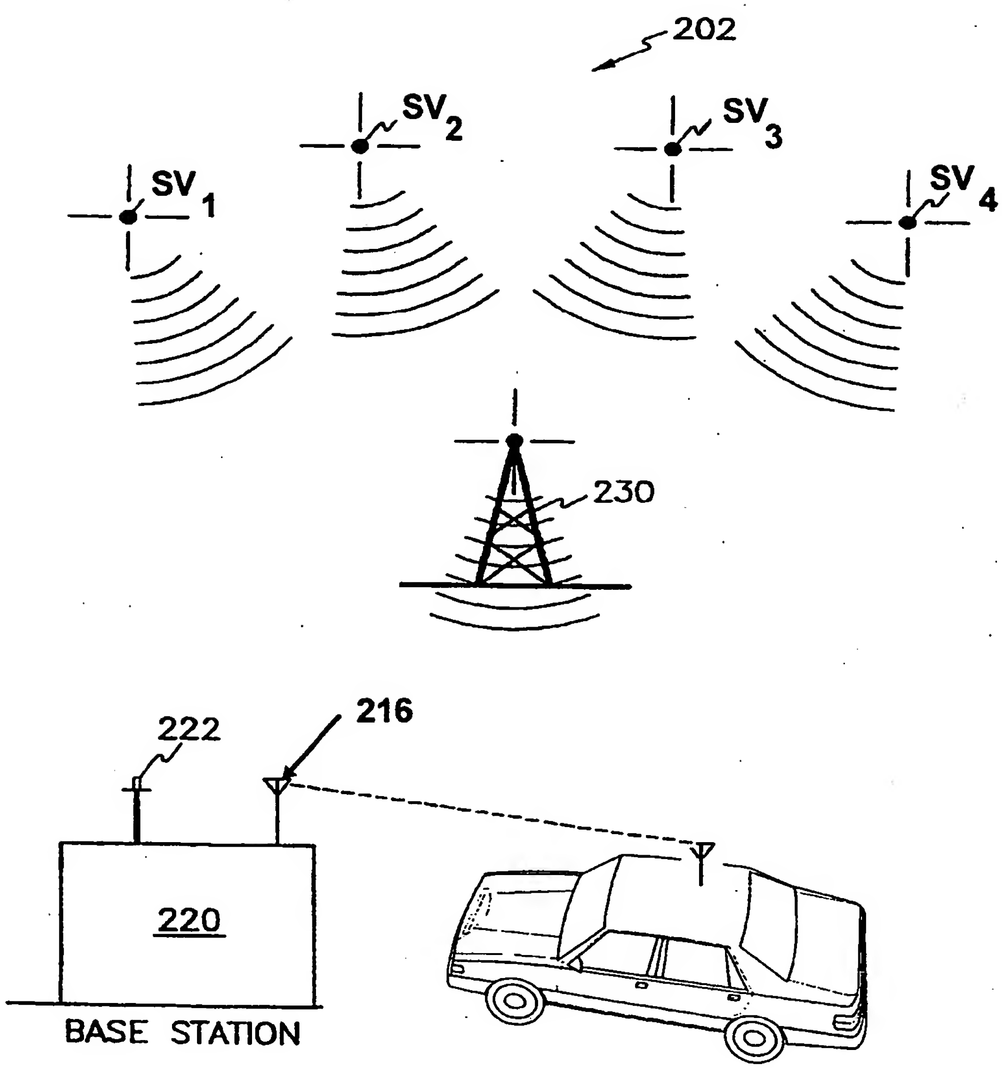
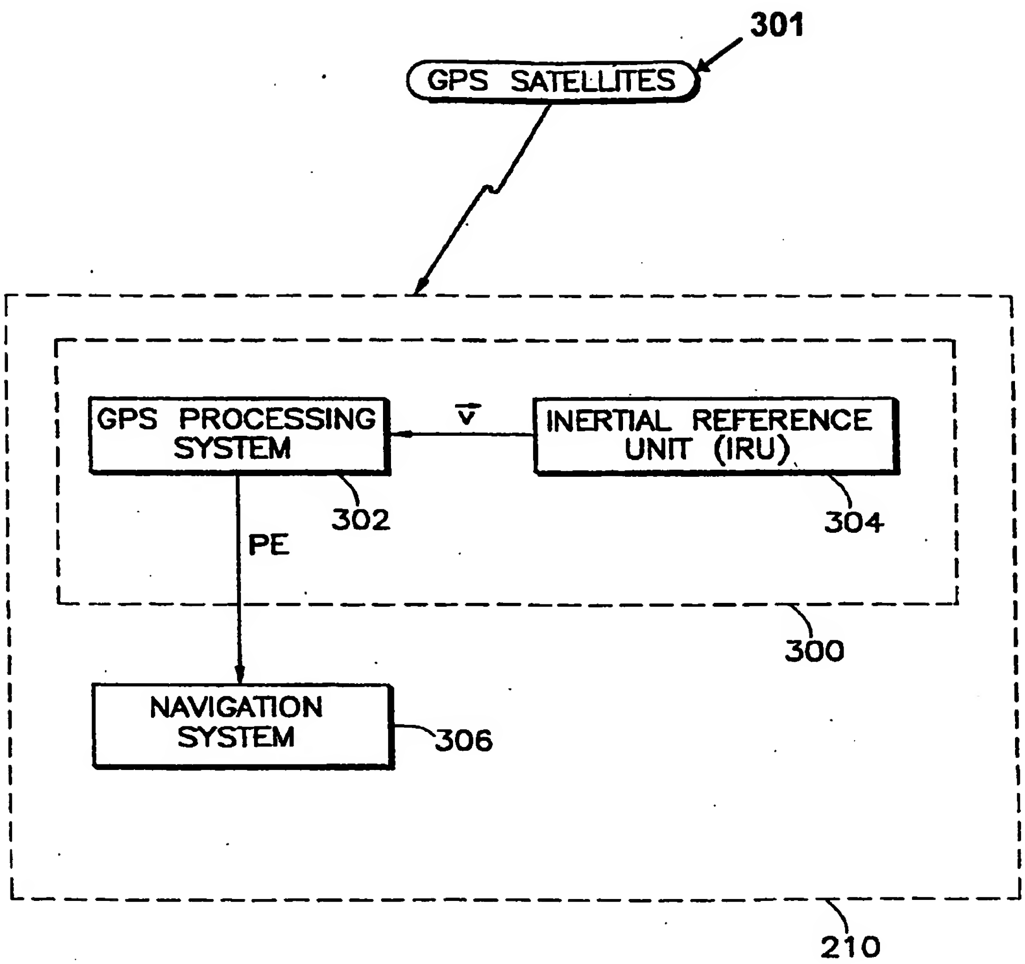


Fig. 2

PRIOR ART



PRIOR ART

Fig. 3

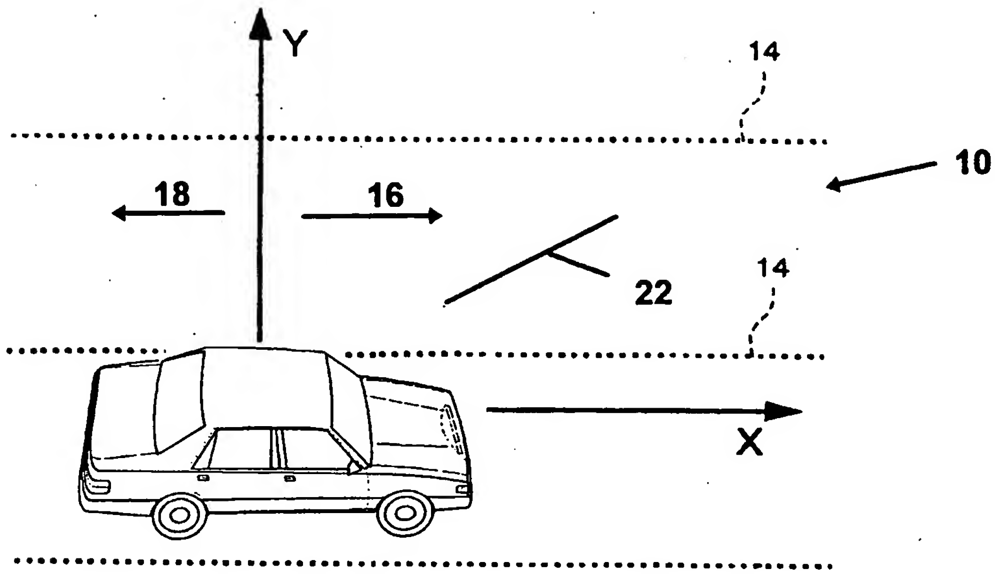


FIG. 4

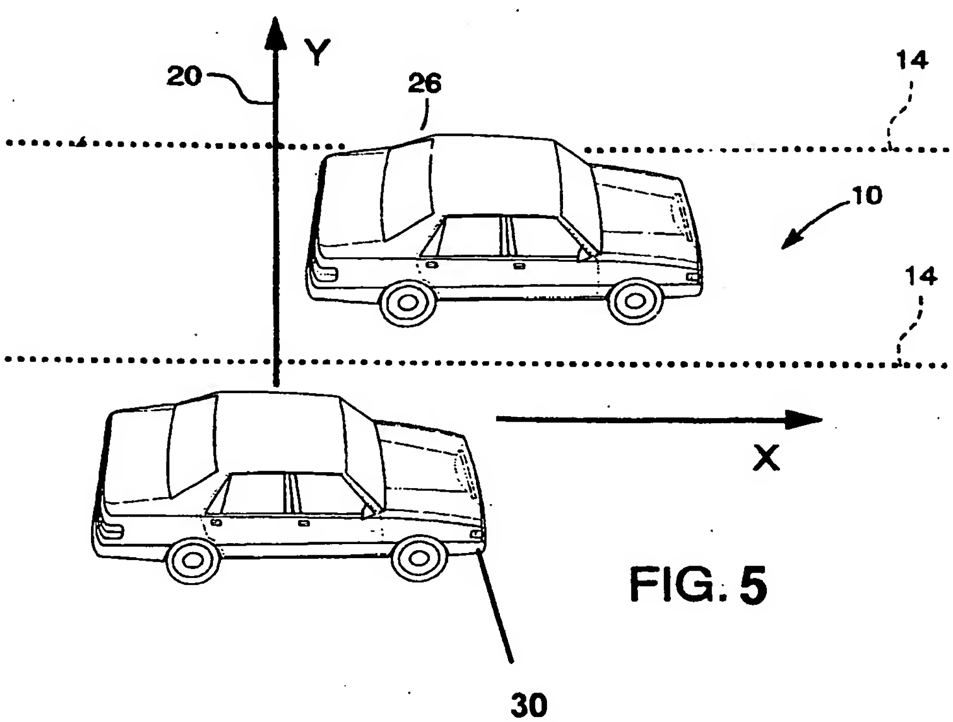


FIG. 5

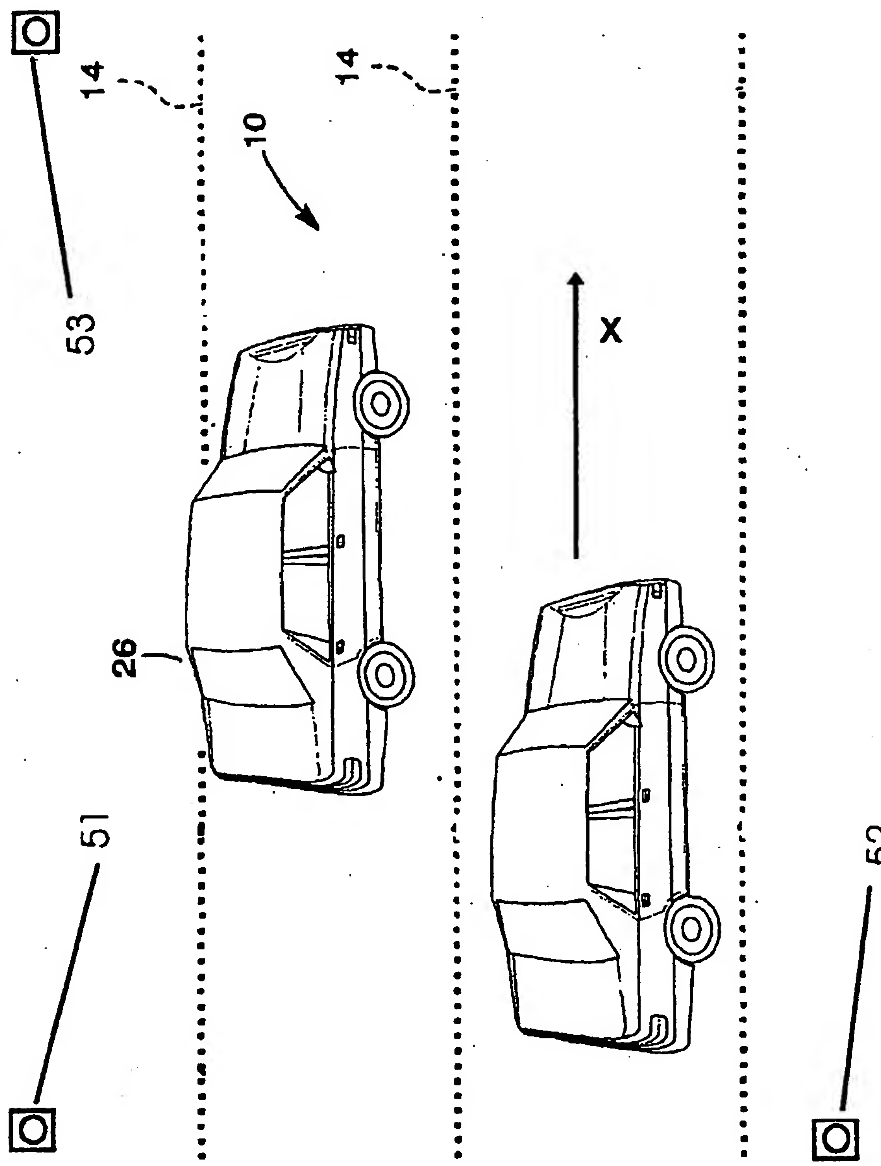


FIG. 6

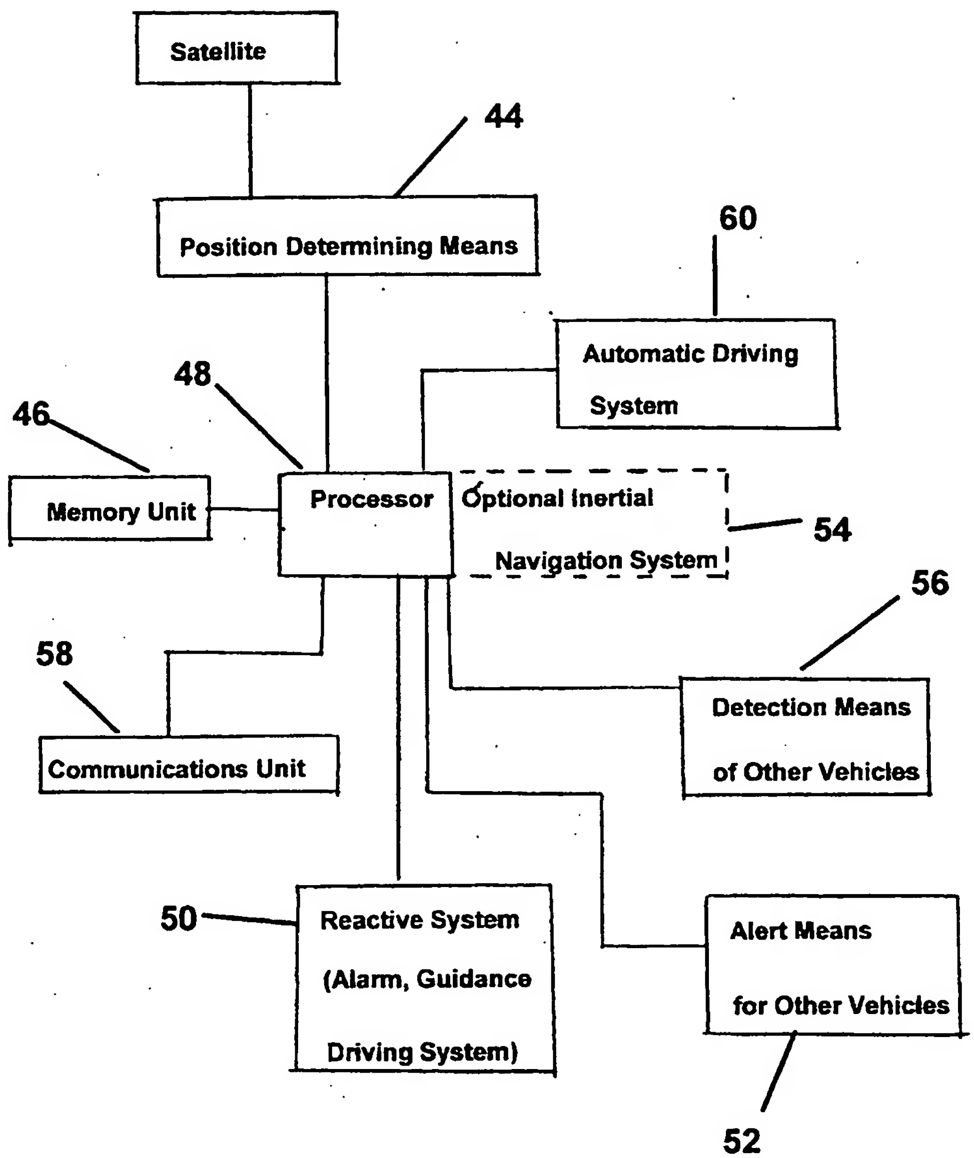

Satellite
44
Position Determining Means
60
Automatic Driving System
48
46
Memory Unit
Processor
Optional Inertial Navigation System
54
56
58
Detection Means of Other Vehicles
Communications Unit
50
Reactive System (Alarm, Guidance Driving System)
Alert Means for Other Vehicles
52

FIG. 7

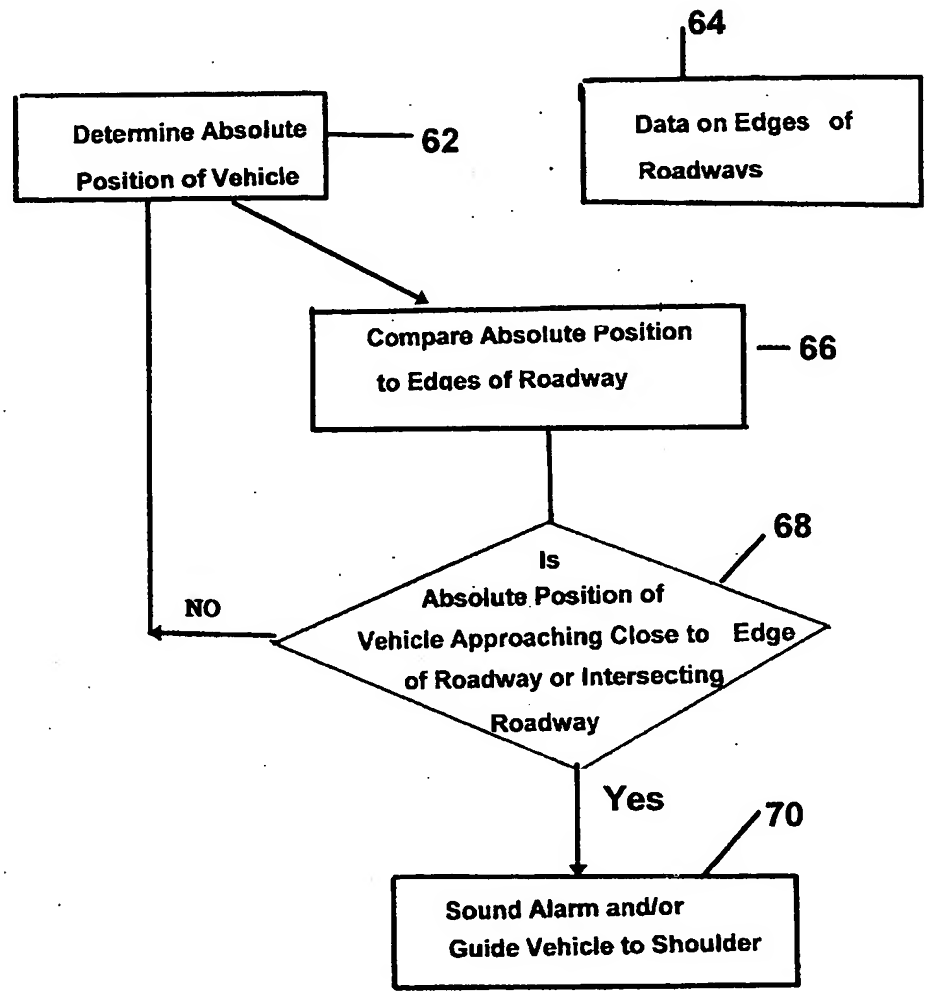

64
Data on Edges of Roadwavs
Determine Absolute Position of Vehicle
62
Compare Absolute Position to Edqes of Roadway
66
68
Is Absolute Position of Vehicle Approaching Close to Edge of Roadway or Intersecting Roadway
NO
Yes
70
Sound Alarm and/or Guide Vehicle to Shoulder

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/06236

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G01C 21/26, 21/30
US CL : 701/301, 208, 213; 342/357.08, 357.13
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 701/301, 208, 213, 45, 215, 220, 217; 342/357.08, 357.13, 357.06, 357.17, 71; 340/435, 436

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,381,338 A (WYSOCKI et al.) 10 January 1995	1, 9, 22
A	US 5,450,329 A (TANNER) 12 September 1995	1, 9, 22
A	US 5,699,056 A (YOSHIDA) 16 December 1997	1, 9, 22
A	US 5,841,367 A (GIOVANNI) 24 November 1998	1, 9, 22

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 APRIL 2000	09 MAY 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	MICHAEL J. ZANELLI
Facsimile No. (703) 305-3230	Telephone No. (703) 308-1113